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Rearing of Marine Fish Larvae in Japan

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Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa, Canada

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IDRC-TS47e

Rearing of marine fish larvae in Japan. Ottawa, Ont., IDRC, 1984. 109 p. : ill.

/Salt water fish/, /fish culture/, /fish production/, /Japan/, /feeding/, /animal diseases/, /bibliography/, /statistical tables/.

UDC: 639.3.04(520) ISBN: 0-88936-406-0

Microfiche edition available

IDRC-TS47e

Rearing of Marine Fish Larvae in Japan

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FOREWORD

Many tropical developing countries are interested in marine finfish culture. At a recent regional workshop held in Singapore in 1980, and sponsored by the International Development Research Centre (IDRC), on "Induced Fish Breeding in Southeast Asia," and through discussions with a number of IDRC-funded projects on the same subject, a strong desire was expressed for further information on the most suitable approaches, facilities, and equipment for the improved larval rearing of many marine finfish species. The presentation by the second author of this text, Dr K Fukusho, at this workshop aroused considerable interest to make further details on Japanese experience in this area available in English.

Subsequent examination indicated that there was no single text available in Japan suitable for the needs of developing countries. The authors kindly agreed to make a detailed literature review of the available information, almost all of which was only available in Japanese, and to produce this summary account of the state of this art in Japan today. This work took about 12 months to complete and the authors are to be commended for their diligence as well as their perception of the type of material that would interest developing countries.

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ACKNOWLEDGMENTS

We are grateful to Takashi Hisamune, President of the Japan Fisheries Resource Conservation Association, and his staff for providing us with the Association's publications on mariculture in Japan. The information we gained from these publications proved valuable in the writing of this report.

The Japan Sea-Farming Association also gave us its publications with production statistics on mariculture in Japan. We are especially indebted to the Association's staff at the Tokyo headquarters.

We are also grateful to Professor Shiro Fujita and Dr Yoshimitsu Ogasawara of the Tokyo University of Fisheries for their kind suggestions and other assistance in the preparation of the section on the basic principles in the rearing of marine fish larvae and the bibliography.

INTRODUCTION

The rearing of marine fish larvae has two major objectives. The first is the production of fingerlings that are further reared in captivity to marketable size fish, are used for restocking, or are

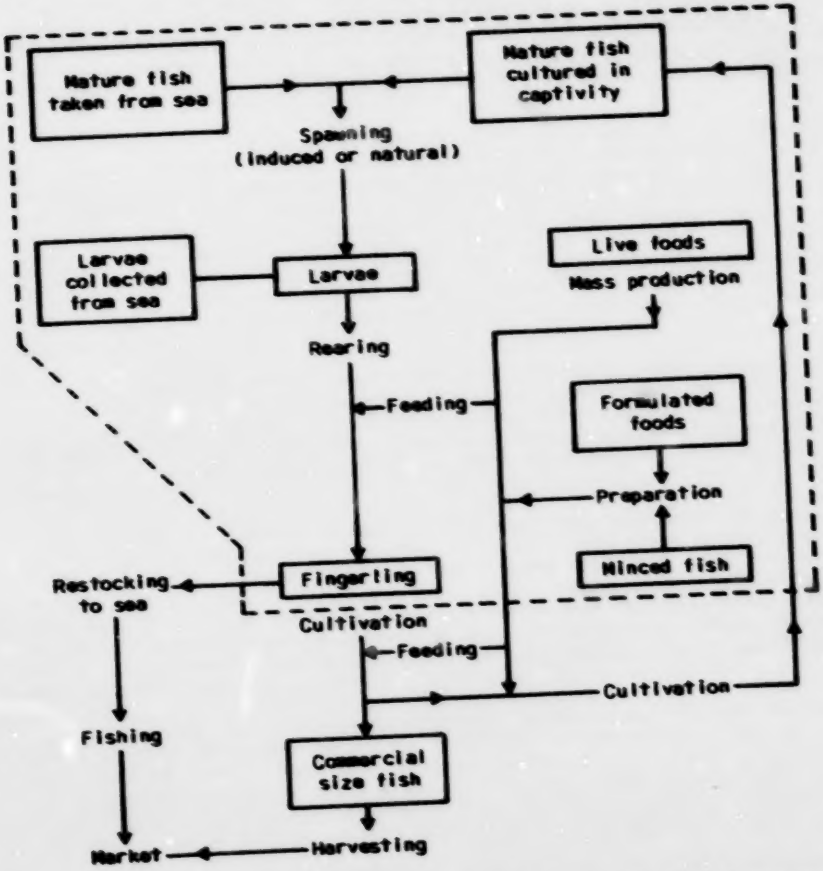

Fig. 1. General scheme of marine fish culture as practiced in Japan. (The section within the dotted line refers to those subjects covered in this publication.)

liberated into the sea. The second objective consists of purely biological purposes such as the study of the morphology, ecology, and ethology of larval fish, their taxonomy, population dynamics analysis, and genetics.

This publication deals mainly with the first objective. Specifically, it discusses the Japanese biotechnology used in the rearing of marine fish larvae for the mass production of fingerlings. The purely biological aspects of this subject are not dealt with unless they are directly related to the problem at hand. The different processes involved in marine fish culture, as it is practiced in Japan, are presented in Fig. 1. The specific processes that are covered are enclosed within the dotted line.

This publication includes three main parts: an introduction to aquaculture in Japan, the basic principles involved in the rearing of marine fish larvae that have been developed in Japan, and the application of these techniques to the larval rearing of selected species of fish. Sources are provided at the end of each section with full bibliographic detail in the reference list.

AQUACULTURE IN JAPAN

Throughout Japan many studies and experiments have been carried out on aquaculture in seawater or on mariculture of fish, molluscs, crusteceans, and seaweeds. Total production through mariculture amounts to a little less than 10^6 t/year (Table 1). This includes roughly 10% of the total production of fisheries in operation throughout the country, which indicates the importance of mariculture to Japanese food production. In mariculture products, seaweeds (51%) make up the largest portion followed by molluscs (32%), fish (17%), and, finally, crusteceans (less than 1%) (Table 1).

In Table 1 the cultivation of fish is characterized by a continuous increase in the amount produced year after year (nearly a fourfold increase within a 10-year period), an increase not seen in the amount of other seafood produced in Japan. This fact clearly shows the improvement of techniques resulting from repeated experiments and experiences. Among the many species of fish cultivated, the amount of yellowtail produced (more than 100,000 t/year) surpasses that of the other species, and is more than that caught by fishing operations. Red seabream production comes next with more than 10,000 t/year.

Increased fish production through mariculture as shown in Table 1 is believed to have resulted from repeated experiments and studies conducted by various agencies found all over the country. These 70 or so agencies include prefecture fisheries stations, sea-farming associations, sea-farming centres, university laboratories, and private hatcheries.

At least 60 species of marine fish have been subjected to spawn taking and larval rearing to the level of large-scale production. Table 2 lists 38 species on which experiments have been conducted or on which production efforts are being made. Among these, 17 species have been identified that are presently cultivated to marketable size or their fingerlings restocked to the sea. Other species (about 25 or so) have also been experimented on to varying degrees, but these have not been included in the table.

Since 1962, experiments in crossing by intraspecific and intrageneric forms have been conducted to attain hybrid vigour. To date, six forms of hybrids have been produced successfully: *Pagrus major* × *Acanthopagrus schlegeli*, *Pagrus major* × *Sparus sarba*, *Pagrus major* × *Evynnis major*, *Oplegnathus fasciatus* × *O. punctatus*, *Seriola quinqueradiata* × *S. aureovittata*, and *Seriola dumerili* × *S. aureovittata*.

The F_2 fish derived from these crossings are reportedly superior to the parent species in terms of survival rates and vitality. However, none of these hybrid forms has been used as established stock in rearing fish to marketable size because the results of the experiments

Table 1. Production (t) of fish, shellfish, shrimp, algae, etc. through mariculture in Japan for the past decade.

Year	Fish									Others				Total
	Horse mackerel	Yellowtail[a]	Red seabream	Crimson seabream	Black seabream	Striped jack	Puffer[a]	Ballistid[a]	Others[a]	Shrimp, octopus, and ascidians[a]	Shellfish[a]	Algae[a]	Pearl oyster	
1970	2	43300	460	5	2	36	26	63	16	504	196478	308105	85	549082
1971	24	61743	571	23	1	43	21	44	41	744	205016	339962	49	608684
1972	112	76913	1298	95	13	15	15	149	113	1641	240577	326922	42	647905
1973	348	80269	2506	58	9	30	17	253	179	5385	269570	432217	34	790874
1974	628	92685	3414	85	4	48	8	51	158	6006	273388	503253	30	879761
1975	923	92352	4303	126	6	22	11	17	236	7290	271543	395881	30	772741
1976	721	101619	6453	125	61	69	11	10	187	9490	291258	439860	34	849909
1977	772	114866	8120	193	67	136	18	34	302	8603	296060	432177	39	861389
1978	815	121728	10344	532	112	181	48	28	720	6954	300003	475237	37	917244
1979	1460	154872	12253	204	104	313	74	53	1228	6789	149301	455929	40	882620
1980	2283	149311	14757	133	150	228	69	6	2780	7320	302094	512670	42	991843

[a] Includes more than one species.

Note: The data exclude fingerlings. For the scientific names of the fish species, see Table 2.

Source: Statistics Division, Ministry of Agriculture, Forestry, and Fishery (Bull. 18(3), 1982).

are still considered tentative and the techniques involved in the production of such hybrids are still in much need of refinement when compared to those used on freshwater species.

Sources: Fukusho (1981), Honma (1980), JSSF (1974, 1975), Red Seabream Larval Rearing Research Group (1977), Tanaka (1982), and Uno and Hayashi (1980).

BASIC PRINCIPLES IN THE REARING OF MARINE FISH LARVAE

The topics included in the discussion of the basic principles in the rearing of marine fish larvae are the uses of fingerlings, brood fish, spawn taking, rearing of larvae, feeding, growth, production, diseases and malformations, and the production of live food.

Only the common names of the fish are used here; however, these names and their corresponding scientific names are listed in Table 2. The terminology used for the larvae at different stages of development are:

- Hatchling: This stage comprises yolk-sac individuals;
- Larvae: Refers to individuals after absorption of the yolk sac to the fry stage;
- Fry: This stage begins when the individual has completed metamorphosis, i.e., when the fish takes on the appearance of a subadult; and
- Juveniles: This stage includes larger fingerlings.

Uses of Fingerlings

Fingerlings reared in captivity are used either as seedlings for further cultivation of marketable-size fish or for restocking to the sea. Seventeen species are used as seedlings (Table 2). The successful restocking of fingerlings is limited to one species, the red seabream. Studies on the problems involved in restocking are still at the experimental level.

Brood Fish

Brood fish from which eggs are collected are classified into three categories: fish collected from the sea or natural brood fish, fish collected from the sea and kept in captivity for a given period, and larval fish grown to brood fish in captivity over an extended period of time or cultivated brood fish.

Before the 1950s, the brood fish of many species were collected in natural seawater. In the 1960s, however, with technical advancement and the popularization of mariculture, spawn taking has been practiced more on cultivated brood fish. Now, more than 20 species are reared as brood fish. It should be noted that the distinction between the categories, i.e., natural versus cultivated, does not depend on the species but on various conditions and treatments such as facilities, temperature of the water, localities, and climates, etc.

Table 2. List of the 38 species of Japanese marine fish subjected to artificial spawn taking and larval rearing for the purpose of cultivation in captivity or restocking to the sea. The biotechnology used and the scope the operations differ by species.

Family	Scientific name	Common name		Reference
		English	Japanese	
Salmonidae	Oncorhynchus keta	Chum salmon	Seke	Honma (1980)
Hemiramphidae	Hemiramphus sajori	Japanese halfbeak	Sayori	Oya and Oka (1981)
Scorpaenidae	Sebastes schlegeli[a]	Black rockfish	Kurosoi	Hoshiai (1977)
	Sebastes inermis[a]	Japanese stonefish	Mebaru	Harada (1962)
	Sebastiscus marmoratus[a]	Scorpion fish	Kasago	See the section on larval rearing of selected species
Percichthyidae	Lateolabrax japonicus[a]	Japanese seabass	Suzuki	See the section on larval rearing of selected species
	Lateolabrax latus	Flat seabass	Hirasuzuki	Suzuki and Hioki (1979)
Serranidae	Epinephelus akaara	Red-spotted grouper	Kijihata	Mito et al. (1967)
Sillaginidae	Sillago japonica	Japanese whiting	Shiroisu	Kiyono and Hirano (1973)
Carangidae	Carenx delicatissimus	Striped jack	Shimaaji	Harada et al. (1973a,b)
	Trachurus japonicus[a]	Horse mackerel	Maaji	See the section on larval rearing of selected species
	Seriola quinqueradiata[a]	Yellowtail	Buri	See the section on larval rearing of selected species
	Seriola eureovittata[a]	Yellow amberjack	Hiramasa	Harada et al. (1972)
	Seriola dumerili	Purplish amberjack	Kanpachi	Harada et al. (1970)
Pomadasyidae	Plectorhynchus cinctus	Three band sweetlip	Koshodai	Harada et al. (1974)
	Parapristipoma trilineatus	Three line grunt	Isaki	Yasuda et al. (1962)
Sparidae	Pagrus major[a]	Red seabream	Madai	See the section on larval rearing of selected species
	Sparus sarba[a]	Silver seabream	Hedai	Harada et al. (1967)

	Evynnis japonicus	Crimson seabream	Chidai	Suzuki and Hioki (1979)
	Acanthopagrus schlegeli[a]	Black seabream	Kurodai	See the section on larval rearing of selected species
	Acanthopagrus latus	Yellow seabream	Kichinu	Akazaki and Tokito (1982)
	Girella punctata	Nibbler	Mejina	Suzuki and Hioki (1979)
Oplegnathidae	*Oplegnathus fasciatus*[a]	Striped knifejaw	Ishidai	See the section on larval rearing of selected species
	Oplegnathus punctatus	Spotted knifejaw	Ishigakidai	Harada et al. (1970)
Mugilidae	*Mugil cephalus*[a]	Gray mullet	Bora	Nash et al. (1974)
	Liza haematochelia[a]	Redeye mullet	Menada	See the section on larval rearing of selected species
Siganidae	*Siganus fuscescens*[a]	Dusky spinefoot	Aigo	Fujita and Ueno (1954)
Scombridae	*Auxis thazard*	Frigate mackerel	Hirasodegatsuo	Harada et al. (1973a)
	Auxis rochei	Bullet mackerel	Marusodegatsuo	Harada et al. (1973b)
	Sarda orientalis	Oriental bonito	Hegatsuo	Harada et al. (1974)
	Thunnus thynnus	Black tuna	Kuromaguro	Harada et al. (1973a,b)
	Thunnus albacares	Yellowfin tuna	Kihadamaguro	See the section on larval rearing of selected species
Bothidae	*Paralichthys olivaceus*[a]	Japanese flounder	Hirame	See the section on larval rearing of selected species
Pleuronectidae	*Limanda yokohamae*[a]	Common flounder	Makogarei	See the section on larval rearing of selected species
Balistidae	*Stephanolepis cirrhifer*	Proky	Kawahagi	Fujita (1955)
	Novodon modestus	Black scraper	Umazurahagi	Takami et al. (1969)
Tetraodontidae	*Sphoeroides rubripes*[a]	Tiger puffer	Torafugu	See the section on larval rearing of selected species
	Lagocephalus spadiceus	Palmbranch puffer	Sabafugu	Fujita (1966)

[a] Species cultivated to a marketable size or their fingerlings restocked to the sea.

Note: There are about 25 additional species of Japanese marine fish that have also been subjected to spawn taking and larval rearing.

In practice, the same species may be treated as either natural or cultivated depending on the aforementioned conditions.

The rearing of brood fish, a process usually lasting from 2-3 years until maturation, is done in floating net cages or sometimes in concrete tanks built on land. Usually, brood fish are reared in net cages until they mature, at which point they are moved to a spawning tank and then returned to the cages after spawn taking. Floating cages used for this purpose usually measure 5 x 5 x 5 m (Fig. 2a) and contain 5-7 kg of fish/t of water. Brood fish are fed minced sandlance, scomber, or anchovy, etc. as well as formulated food.

Floating net cages have the following advantages: the water is natural, stocking density is high, the handling of fish is easier, the cages move vertically as required, and the expenses incurred are lower. Concrete tanks on land, although providing easier control of environmental factors, are much more expensive to build.

Spawn Taking

Mature brood fish are transferred to a spawning tank on land. The tank has a capacity of 40-100 t and has an egg-collecting system (Fig. 3). The brood fish are stocked in the tank at a rate of 1 kg of fish/t of water with a sex ratio of 1:1. The eggs spawned in the tank water are transferred to an overflow tube and then to an egg-collecting canal where a collection net is set. The eggs gathered in the net are washed and separated from debris before being transferred to the larval rearing tank. Usually they are transferred to an egg-hatching or incubation tank (see Fig. 4c).

Where eggs are collected by stripping from brood fish selected from catches on board ship, the eggs are fertilized by the wet or dry method, usually in a small container. The inseminated eggs are taken to a hatchery on shore and put into an incubation tank or directly into a larval rearing tank.

The hatching or incubation tank is placed indoors and has a system that provides a sufficient air supply. This tank usually has a capacity of 8-10 t of water. Net cages are hung in the water with a specified number of eggs stocked in each cage. The tank water is kept stagnant but is aerated intensively, and lighting is controlled by dark curtains placed over the tank. The eggs hatched inside the cage are picked up by a siphon, thus ensuring that the hatching rate is accurately calculated.

Commentary Notes

The studies conducted on spawn taking of marine fish up to 1970 have revealed valuable biological and technological information. For example, species like the red seabream, black seabream, silver seabream, and striped knifejaw consistently produced better-quality eggs from cultivated brood fish than from the natural stock. Among species like the yellowtail, Japanese flounder, and flat seabass, cultured brood fish produced eggs similar in quality to those of natural stock provided the proper techniques were used. With the purplish amberjack, yellow amberjack, striped jack, and spotted knifejaw, the cultivated brood fish produced eggs in captivity, but the brood fish derived from natural stock did not spawn in the tank.

Fig. 2. (a) Floating net cages for keeping brood fish (Hiroshima Station). The four cages, each 5 m^2, are set under a single system and each cage is covered by a screen net. (b) Outdoor concrete tanks (Nagasaki Station). The four circular tanks, each with a 100-t capacity, are used for the rearing of fish larvae; the two square 200-t tanks are for cultivation of tigriopus; and the four 40-t square tanks are used for growing rotifer. (c) A portion of the circular tank in (b) in which chlorella is grown.

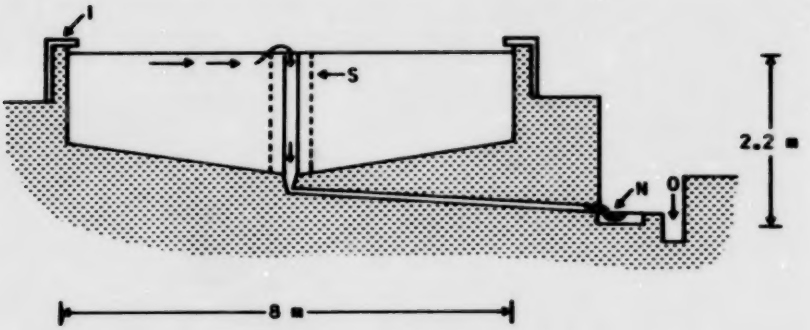

Fig. 3. Diagram of a fish-spawning tank with an egg-collecting system: I = water inlet, S = screen, N = egg-collecting net, and O = water outlet (Yamada 1967 with modifications).

Major factors affecting gonadal maturation and spawning were water temperature, light intensity, oxygen content, and salinity of the water. Table 3 shows the spawning season of 12 species of marine fish in terms of months and optimum water temperature. These species were subjected to repeated experimentation. It should be noted that the seasons and water temperatures shown in the table correspond to actual seasonal variations. Findings showed that failure to adjust the temperature of the water in the tank and sudden changes in temperature or shortened periods of optimum temperature readings resulted in the production of poor-quality eggs or the total failure of spawn taking. In contrast, temperature regulation induced the spawning of red seabream in the tank (see Fig. 11 in the section on larval rearing of selected species).

Unlike freshwater fish under cultivation, there have been no precise data accumulated for marine fish regarding the effects of light intensity on the spawning activity. However, a number of marine fish species in tanks discharged eggs between 15:00 hours and 22:00 hours, with the peak activity occurring around twilight. This finding suggests the adaptation of the egg-laying activity to lower light intensity.

The inducement of spawning by hormone injection, mostly of synahorin, has been done on a number of species. But, so far, among the 60 or so species tested only 15 have spawned after hormone injection. This type of experiment has been aimed at promoting the acclimatization of fish to the artificial conditions in the tank so that they could spawn under such conditions. A similar concept has also been adopted for the rearing of larval fish.

Number of Eggs

The numbers of eggs spawned and eggs existing in the tank at different stages of spawn-taking procedures are estimated in three ways. The first is by the weight method in which the number of eggs in an egg mass weighing 1 g is counted and the total multiplied by the total weight of the eggs collected. The second is the scooping method. Here the eggs are scooped with water and counted and the total volume of tank water multiplied by the number counted in the

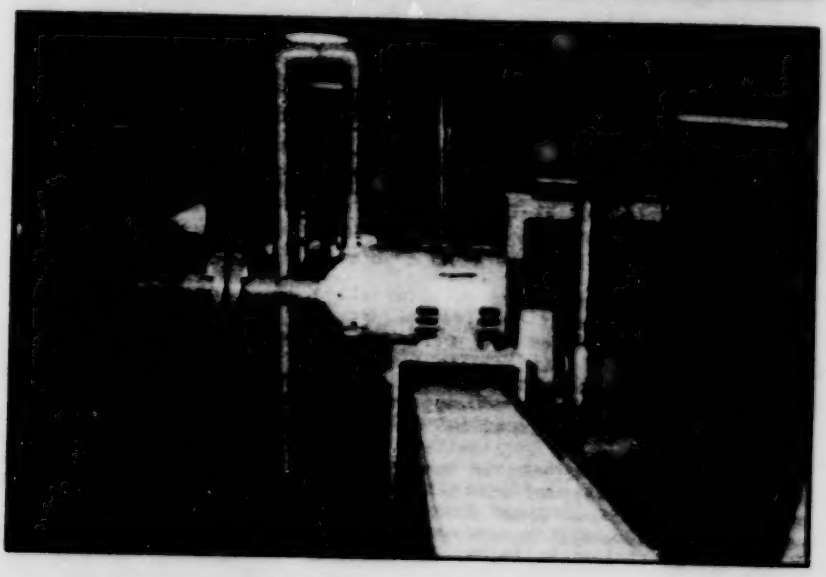

Fig. 4 (a) The octagonal 100-t tanks constructed indoors with water supply pipes and aeration systems at the Aichi Prefecture Sea-Farming Center. These tanks are used for the rearing of larval fish. (b) Automatic bottom cleaner at the Hiroshima Prefecture Fisheries Experiment Station. The machine moves along the wide tank edge and the debris and dead fish on the bottom are collected by suction and drained into the draining canal.

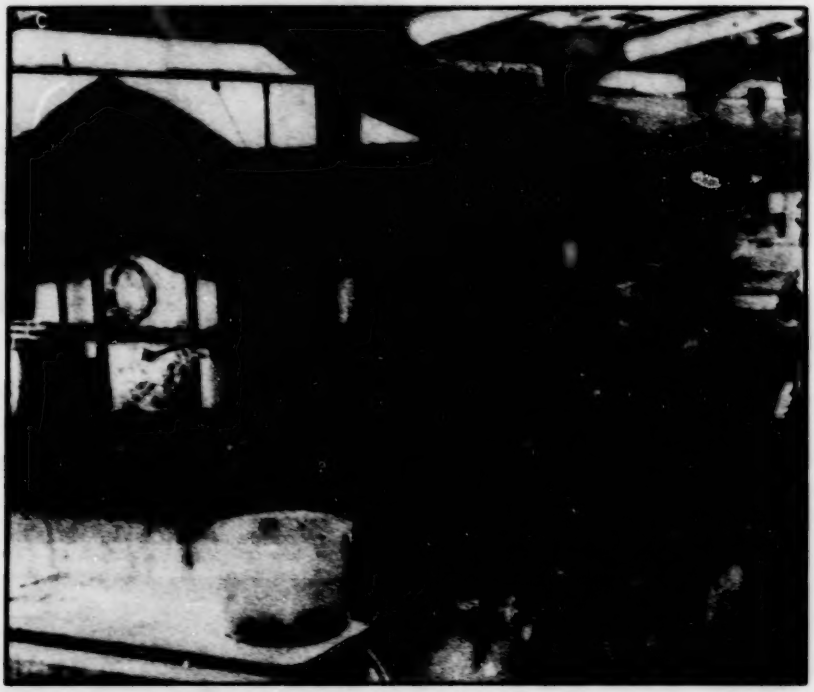

Fig. 4 (c) Red seabream egg incubation tank with an 8-t capacity, constructed indoors at the Nagasaki Prefecture Fisheries Experiment Station. Eggs are placed in 10 nets inserted in the tank and hatch in the tank water aerated through multiple tubings.

unit container. The third method is the volumetric method. The volume of a given number of eggs and the total volume of eggs are multiplied by the number counted in the unit volume.

It is apparent that the number of eggs in a tank counted using any of the methods mentioned is merely an estimation. So far, the weight method has obtained the following commonly accepted results: yellowtail, 1200 eggs/g; redeye mullet, 1300 eggs/g; red seabream, 2000 eggs/g; striped knifejaw, 2800 eggs/g; and common flounder, 4500 eggs/g.

Sources: Davy and Chouinard (1981), Fujita (1975), Fukusho (1981), Harada (1974), Harvey and Hoar (1979), Hirano (1974), Ichiki (1972), and JSSF (1974).

Table 3. Seasons (months) and optimum temperature of water for the spawning of 12 species of marine fish that were acclimatized to spawn in captivity.

Family	Species	Season	Optimum temperature (°C)
Carangidae	Caranx delicatissimus	December-January	15-19
	Seriola quinqueradiata	March-June	18-20
	Seriola aureovittata	May-June	22-25
	Seriola dumerili	May-June	22-25
Sparidae	Pagrus major	March-June	17-21
	Sparus sarba	March-June	17-21
	Acanthopagrus schlegeli	March-June	17-21
	Acanthopagrus latus	October-November	17-21
Oplegnathidae	Oplegnathus fasciatus	May-July	21-26
	Oplegnathus punctatus	May-July	21-26
Bothidae	Paralichthys olivaceus	February-May	14-16
Tetraodontidae	Sphoeroides rubripes	April-May	17-20

Source: Harada (1974) with modifications.

Rearing of Larvae

Of the 600 species listed in the Japan Fisheries Resource Conservation Association bibliography there are 157 families on which biological or fisheries studies of eggs and larvae have been conducted. As shown in Table 2, larval rearing has been done on about 38 species of marine fishes. Now, at least 17 of these species are cultured on a commercial basis by private hatcheries.

There are two types of larval fish used for cultivation: those collected from the sea (natural larvae) and those reared in captivity. The natural larvae of a number of species were used before about 1950 but were not used extensively afterward. There are two major reasons for this. First, the collection of larvae from the sea requires a great amount of labour and expense. Furthermore, the amount of available sea-collected larvae is not sufficient to meet the present demand. Moreover, the availability of natural larvae is affected by the weather, fluctuations in the larval population, and other factors. Second, techniques for the artificial production of larval fish have improved markedly since 1950. In fact, mariculture today does not depend on natural larvae except in the cases of yellowtail, black seabream, and a few others.

The rearing of marine fish larvae in Japan was developed for a number of reasons. First, the mature fish as well as larvae and fingerlings fetched high prices in the marketplace. Second, the larvae had high growth and survival rates. Third, a substantial supply of food, both live and processed, was available at a low cost.

Larvae are reared for restocking to the sea because large amounts can be produced economically. In addition, fingerlings must adapt to the natural environmental factors such as oceanographic conditions,

availability of food organisms, competition, and predators and they must be marked for identification purposes to evaluate survival.

In practice, the rearing of larval fish, from hatchlings to fingerlings or juveniles, is divided into two, the primary and secondary phases. The first phase takes place in concrete indoor or outdoor tanks and the second phase in floating net cages or larger tanks. Sometimes, the second phase occurs in emptied salt beds or unused eel ponds on the beach.

Primary Phase

The concrete tanks, indoor or outdoor, used for the primary phase of larval fish rearing have a capacity of 0.5-200 t. Although they have different designs, they are always structured so that there is a smooth flow of water in the tank. Two examples of larval fish rearing tanks with different designs are shown in Figs 5 and 6. The sizes of the tanks used for red seabream larval rearing are presented later (see Table 14).

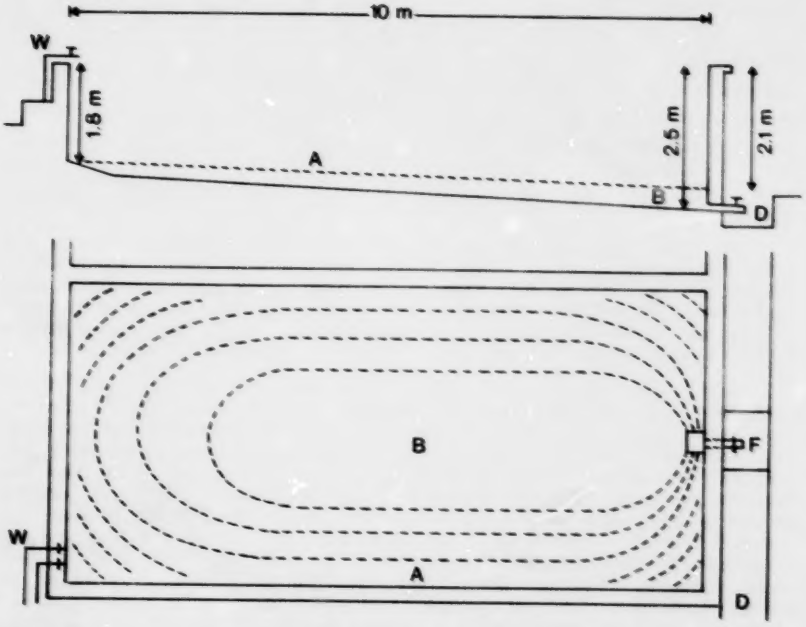

Fig. 5. Design of a rearing tank for red seabream larvae showing the inclination of the tank bottom: A = bottom level along the base of the tank wall, B = bottom level on the mid-part of the tank, D = water draining canal, F = fish-collecting area, and W = water supply tubes, 50 and 100 mm diameter (Hirata et al. 1977a with some modifications).

The rectangular tank (Fig. 5) has a declined bottom from one side to the other and a swollen central bottom graduated from four side walls. The bottom is opened to a water draining canal by a tube that

opens in a depressed square in the draining canal. The second example of a rearing tank (Fig. 6) is also rectangular but the four corners are cut and a central wall divides the tank into two sections with each section having a declined bottom. There are two depressions on opposite sides. The depression is opened to a draining canal by two tubes. In both tanks the larval fish are collected in the depressed portions (marked F in the figures) by draining the tank water.

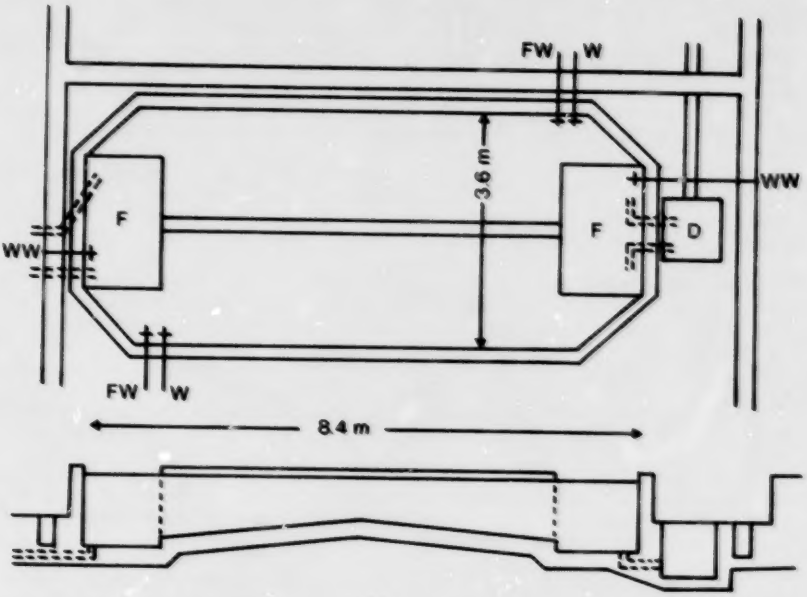

Fig. 6. Design of a rearing tank for seabream larvae featuring a middle-wall separating the tank into two sections, with each section having a fish-collecting site, bottom inclination 1/20, and cut corners: F = fish-collecting site, D = water draining canal, FW = filtered water supply tube, W = untreated water supply tube, and WW = warmed water supply tube (Hirata et al. 1977a with modifications).

The rearing tank is always equipped with water supply tubes, usually one for each of three kinds of seawater - filtered, fresh, and warmed. There is also an aeration system consisting of a compressed airpump and conveying tubes ending in an air stone. For indoor tanks the roof is covered by glass or plastic windows with dark curtains. Dark curtains are also set over the outdoor tanks.

The supply of seawater to the tanks, whether located outdoors or indoors, is provided by facilities that include a water-collection site located in the sea beyond the low tide line, piping to the pumping room on the shore, and a water filtration system. The water reserve tank, which is always needed in conjunction with the water supply system, is usually located on land at a level higher than that of the rearing tank to ensure a smooth flow of water. A water discharge system is also included in the facilities.

All the facilities mentioned are used and operated for the management of the tank water. A siphon tube is used to drain small amounts of tank water. The end of the siphon in the tank is covered with a net to prevent loss of the larval fish. The mesh size of the net tube is adjusted according to the size of the larvae.

Before starting the larval rearing process, it is a common practice to add chlorella to the tank water to naturalize the water and to provide a supply of natural food that is in turn consumed by live food such as rotifer and copepods. The concentration of chlorella is usually 300-400 pieces/cc of water. The overgrowth of chlorella and diatoms (contained in fresh seawater), which is encouraged by strong sunlight, leads to an increase in the pH value or oversaturation of oxygen in the tank water. These unfavourable conditions are regulated or eliminated by moving the tank water and drawing the dark curtains.

Other factors in the tank water that need adjustment are temperature and salinity. The temperature for the proper growth of fish larvae varies by species and it is adjusted based on the data shown in Table 3. The salinity is usually kept at 1.020-1.025 sp gr.

An important task in the management of the tank water is the cleaning of the tank bottom where dead fish, unconsumed food, and debris of other origins are deposited. The amount of these deposits is correlated positively to the density of the larvae. The tank bottom is usually cleaned by the use of a siphon or some other appropriate device; for instance, in some places a modified vacuum cleaner developed especially to meet this specific problem is used (Fig. 4b).

The stocking rate of the larvae into the tank also varies by fish species and by a number of other factors. Usually, however, 10,000-50,000 larvae/t are placed in tanks with a 10-30-t capacity and 4000-10,000 larvae/t in 150-200-t tanks.

The collection of larvae that have grown to the required size or the harvest of the crop in the tank is done in four steps. First, the tank fish-collecting system is prepared. Second, the tank water is drained using a siphon or an air-lifting tube and the larvae left in the tank are collected by a dip net. Third, a long glass tube is put into the water in areas where the larval fish are concentrated. Fourth, at night, the larvae are attracted to the surface of the water by an artificial light and from there they are picked up by a dip net.

Secondary Phase

The floating net cages used for larval rearing in the secondary phase vary in size and structure depending on several factors. A cage usually measures 2 x 2 x 2 m or 3 x 3 x 3 m and has a net with a mesh size of 2-6 mm that is adjusted as the larvae grow. In most cases, the cages are covered by a net, the upper edges of which are reinforced by canvas to keep the fish from jumping out. Often, artificial lighting is placed over the cage to attract planktonic organisms into the cage at nighttime and it also serves to stimulate the feeding activity of the fish.

Commentary Notes

The larvae reared in the tanks (primary phase) and those in the floating net cages (secondary phase) vary in size according to the

species of fish, but it is apparent that the larvae in the floating net cages are larger. The primary and secondary phases differ distinctly from each other in terms of the food materials supplied to the larvae selected on the basis of the feeding requirement of each group. (This is explained in greater detail in the following section on feeding.) The major food items supplied to the larvae in tanks are live food, whereas those supplied to the larvae in the net cages are limited to processed food. Live food not completely consumed by the fish does not cause the spoilage of tank water. In the floating net cages, the processed food that remains uneaten moves through the net and out to the sea, thus preventing pollution of the water inside the cage.

Sources: Bardach et al. (1972), Dotu (1965), Fukusho (1980), JFRCA (1980), Hirata et al. (1977), IDRC/SEAFDEC (1980), Red Seabream Larval Rearing Research Group (1977), Takemura (1964), and Uchida et al. (1958).

Feeding

Larval fish reared in the tank are fed mainly with various types of live food. Feeding is managed so that it matches natural conditions as closely as possible. Efforts are also made, however, to acclimatize the fish to the tank environment. To accomplish this many studies have been made on the subject of feeding, i.e., its material, amount to be supplied, frequency, nutritive value, feeding behaviour, etc. In these studies the aquarium set shown in Fig. 7 has been adopted.

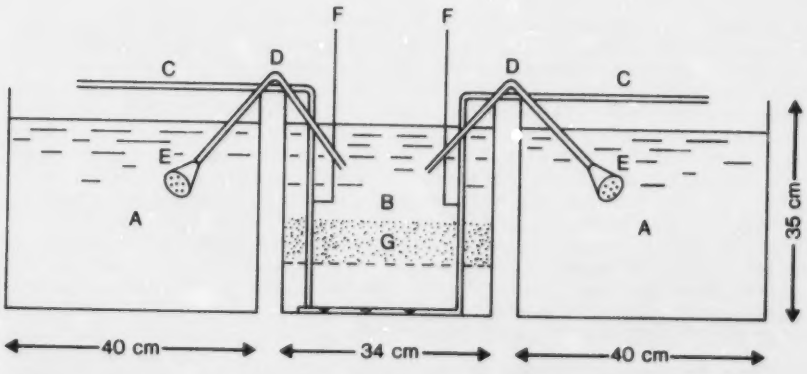

Fig. 7. Experimental aquaria with a water circulation system for rearing larval fish: A = aquarium (40 x 40 x 35 cm), capacity of water 50 L/30 cm deep; B = filtration tank (34 x 34 x 35 cm); C = glass tube for air lifting; D = siphon ending on funnel sealed by a sieve E; F = aeration tube; and G = filtration sand. The water is moved 1-3 L/min by controlled air pressure, and the temperature is kept constant by an electric heater with a thermostat (Dotu 1965 with some modifications).

The principles guiding the feeding of larval fish in tanks or net cages are: (a) food is consumed completely, (b) the food is well digested keeping the fish healthy and growing normally, and (c) production and supply of this kind of food are economically feasible.

Live Food

Live food is used only in primary-phase rearing. The accounts that follow concentrate more on the food supplied to the red seabream larvae, which is the species that has been the subject of more experiments than any other species of marine fish.

The list of live food only includes those forms adopted so far. The planktonic organisms that are carried by seawater into the tank are numerous, thus, accurate identification has not yet been completed. In the list, the species marked with an asterisk indicate that mass production in captivity has been achieved. It should be pointed out that chlorella is supplied to the tank with the main objective of naturalizing the water, although it also serves as food for the larval fish:

- Rotatoria: Rotifera Brachionus spp.*
- Mollusca: Pseudolamellibrachia Crassostrea gigas.*
- Crustacea: Euphyllopoda Artemia sp., Cladocera Penilia avirostris,* Evadne tergestina, and Podon polyphenoides. Copepoda Sinocalanus tenellus,* Pseudodiaptomus inopius, P. marinus,* Eurytemora pacifica,* Acartia clausi,* A. longiremis, Oithona brevicornis,* O. similis, Eupterpina acutifrons, and Tigriopus japonicus.* Cirripedia Balanus spp.
- Chlorophyta: Chlorophyceae Chlorella spp.*

Among the different kinds of live food, especially those supplied in the initial stage in the rearing of nearly all the marine species, the most important one is rotifer (Brachionus spp.). The demand for large amounts of rotifer has encouraged the development of the technology needed for its mass production in captivity. Rotifer is classified according to the different materials used for its cultivation: (a) rotifer fed with fresh or dried chlorella, (b) rotifer fed with bakers' yeast, (c) rotifer fed with bakers' yeast mixed with chlorella, (d) rotifer fed with bakers' yeast and immersed in seawater containing chlorella for different periods of time, and (e) rotifer fed with bakers' yeast in which fatty acids have been assimilated. A number of experiments conducted to evaluate these five types of rotifer have revealed that rotifer fed with chlorella alone or with bakers' yeast alone are inferior in many ways. Therefore, these two types of rotifer are not used at present.

The trochophore larvae of the oyster was used for initial feeding for a long time before the mass production of rotifer started. Now, however, the oyster larvae are seldom used in the larval rearing of fish because their food value is nearly equivalent to that of the rotifer. In addition, the production of oyster larvae requires more complex techniques than those required for rotifer production. The economics of oyster larvae production is also a consideration.

The brine shrimp (Artemia sp.) is one of the most common items used in larval rearing, especially of aquarium fish. This is probably

because of its easy availability. For the rearing of marine fish larvae, artemia is also used for a number of species, but it is used only for short periods or in combination with copepods such as tigriopus. Experiments have shown that feeding with artemia alone results in a rather high mortality rate of fish larvae.

The planktonic live food adopted so far include more than 10 species (see list). These are commonly fed to the larval fish in the stages before metamorphosis until shortly after, but always in combination with other items such as artemia and other types of processed food. With the exception of several species (marked with an asterisk in the list given earlier), planktonic live food is collected from seawater. The collection is done in different ways, but the artificial lighting method is the most effective and the most widely adopted. In this method lighting consists of an electric bulb that is placed on the water surface or immersed in the water at nighttime. The organisms attracted by the light are collected by a pump or by an air-lifting tube.

The amount of live food fed to the fish larvae varies depending on the species of fish reared and many other factors. Thus, it is difficult to express these amounts by formulas or other standardized methods, even for the more commonly used rotifer. There are a number of statistics recorded on the subject. A few examples are introduced in the next section (see Tables 11, 15, and 20, and Fig. 16). For feeding practices, the key point is the close observation of larval fish behaviour in the tank, e.g., feeding behaviour, pattern of food selection, swimming and searching action, growth rate, and schooling. Generally, the proper amount of live food supplied daily is equal to 80-100% of the larval fish weight.

Processed Food

Toward the end of the rearing period in the tank the fish larvae are fed with processed food in addition to live food. The larval fish reared in net cages are fed only with processed food divided into minced food, which is prepared at the hatcheries, and formulated food, which is factory made and available commercially.

Minced Food

In the preparation of minced food, fish, shrimps, or clams are minced and made into a paste. Then flour and usually small amounts of vitamins are added. Raw materials often used are fish such as sandlance, horse mackerel, scomber, yellowtail, etc.; shrimps (Penaeopsis); and clams (Paphia). The choice when using these materials depends mainly on their availability and cost. Experience has shown that minced clams stay fresh longer than minced fish in the same tank water.

The preparation of minced food on site requires fewer facilities and less space and labour; therefore, it is more economical than live food. Consequently, it is much better to feed larval fish in the tank with processed food instead of live food. However, experiments carried out so far have shown that larval fish do not grow normally in the tank when they are fed with processed food alone. This is probably due to nutritional reasons as well as the feeding behaviour of the fish. Further investigation is needed on the subject.

Table 4. The two types (spray-dry method and vacuum-dry method) of formulated food used for the feeding of experimentally produced larval marine fish showing the method of processing, materials used, and the main characteristics of each.

	Spray-dry method		Vacuum-dry method	
Procedure materials (%)	Shrimp (fresh)	20	Frozen sandlance	30.6
	White fish (fresh)	30	Shrimp (fresh)	30.6
	Wheat gluten	15	Egg yolk	10.2
	Milk powder	10	Wheat gluten	20.5
	Egg yolk	5	Grape sugar	2.0
	Cow liver	5	Vitamins mixed	6.1
	Soybean oil	5		
	Grape sugar	5		
	Vitamins mixed	5		
Characteristics of granules				
Shape:	Nearly spherical		Nearly spherical	
Size:	50-100 m		250-420 m	
Solubility:	Not dissolved in 24 hours		Not dissolved in 10 hours	
Swelling:	15-20% increase in size		20-30% increase in size	
Sinking:	5-10 cm/min		1.5 cm/min	

Source: Sato et al. (1971) with modifications.

Table 5. Growth rates of 18 species of marine fish larvae reared in captivity for 2 months shown by body length (mm) measured on the given days after hatching.

Family	Species	Days after hatching									Water temperature (°C)
		5	10	15	20	25	30	40	50	60	
Gadidae	Theragra chalcogramma	6.0	--	6.2	--	6.7	--	7.0	--	10.0	6-10
Hemiramphidae	Hemiramphus sajori	8.0	10.5	13.6	14.8	17.1	17.8	26.0	30.0	40.0	23.0-32.0
Scorpaenidae	Sebastiscus marmoratus	3.8	4.3	5.1	5.8	6.1	6.4	7.0	--	--	13.0-14.0
Percichthyidae	Lateolabrax japonicus	3.3	6.5	7.4	8.8	9.6	11.7	14.2	18.8	24.2	11-18
Carangidae	Seriola quinqueradiata	4.5	6.0	7.7	12.1	--	30.0	--	80.0	100.0	21.0-27.5
	Trachurus japonicus	3.8	4.0	4.5	5.0	7.8	11.0	26.0	38.0	48.0	16.0-22.0
Sparidae	Pagrus major	3.4	4.2	4.8	7.3	8.9	9.8	15.0	30.0	--	16.0-21.0
	Acanthopagrus schlegeli	2.7	3.3	4.8	6.4	8.0	10.0	21.0	30.0	--	17.0-21.0
Opiognathidae	Opiognathus fasciatus	3.5	4.4	5.3	8.7	--	10.0	27.0	45.0	70.5	23.3-27.8
Mugilidae	Liza haematochelia	3.5	5.5	7.5	10.5	--	15.4	20.1	26.0	38.5	19.0-23.6
Siganidae	Siganus fuscescens	--	4.7	12.0	20.0	41.0	72.5	--	--	130.0	26.8-31.4
Scombridae	Auxis thazard	--	5.4	--	--	50.0	51.5	60.0	--	--	22.6-28.6
	Auxis rochei	--	5.2	7.8	40.0	--	--	140.0	--	--	22.5-27.5
	Auxis tapeinosoma	--	2.0	--	4.8	--	7.0	14.0	15.0	16.0	25.0-29.0
	Thunnus albacares	4.0	6.2	7.0	8.5	--	--	--	--	--	26.0-29.0
Bothidae	Paralichthys olivaceus	3.0	5.6	6.4	8.4	10.0	--	13.2	--	25.0	12.3-16.5
Pleuronectidae	Limanda yokohamae	4.1	5.0	--	6.8	--	8.0	9.6	--	21.1	10.0-15.8
Tetraodontidae	Sphoeroides rubripes	3.0	4.5	5.6	6.8	8.3	9.8	20.0	32.0	45.0	16.0-21.0

Source: Fujita (1975) with modifications.

Formulated Food

There are several kinds of formulated food manufactured for the feeding of mature fish including the yellowtail, red seabream, eel, and freshwater species. In contrast, formulated food for the feeding of marine fish larvae is limited because only a few kinds have been developed experimentally.

Table 4 shows two kinds of formulated food in terms of the processes and the raw materials used. The first process is the spray-dry method in which well-mixed materials are sprayed into hot air and then dried. The second process is the vacuum-dry method in which the materials are dried under low pressure and temperature. Capsulated larval food appears to be better than live and processed food in many respects; however, this is still being investigated.

Like live food, the amount of processed food given to the fish larvae varies depending on a number of factors. In the case of processed food, the problem is further complicated because this type of food is given in the latter portion of the primary-phase rearing while some live food usually still remains in the tank water. There are some records on the subject (see Table 11 and Fig. 16) but no formulas or standardization has been established. Nevertheless, the amount of processed food given is usually regulated by observing the behaviour of the larval fish in the tank in the same way that the amount of live food given is regulated. The food supply for larvae reared in floating net cages is limited to minced food. Again, the amount of food supply is adjusted according to the observed behaviour of the fish in the cage. In practice, however, the total amount of minced meat usually prepared amounts to about twice the weight of the fish in the cage.

Sources: Anraku (1979), Hunter (1981), Masters (1975), May (1971), Ogino (1980), Shiroto (1975), Tanaka (1968, 1969, 1975), Tanaka and Endo (1979), Teramoto and Kawamori (1980), and Watanabe (1982).

Growth

The growth of larval fish reared in tanks or in net cages varies according to species and within species depending on factors such as feeding, temperature of water, light intensity, and others. Table 5 shows the growth of 18 species reared in tanks and then transferred to net cages. The table shows the growth rates by species and the water temperature suited for the growth of the different species.

An analysis of the figures in Table 5 combined with the spawning season of the species (see Table 3) shows that, in general, the species that spawn in the summer months tend to grow faster. Spring to early summer spawners tend to grow more slowly. The growth of fall/winter spawners is slow. It has also been noted that in most of the species that have been experimented on the slope of the growth curve shows a distinct rise at about the same time that greater amounts of processed or formulated food are given.

Sources: Fujita (1975), Kawamoto (1978), and Red Seabream Larval Rearing Research Group (1977).

Production

The production of larvae is indicated by the number of the fish remaining or surviving in the tank or net cage at the end of the rearing operation. Survival of the larvae is determined by the number of larvae that have died. This discussion on production, then, deals with the larvae's survival and mortality rates. The method of counting larval fish is also briefly discussed as well as the transportation of the larvae from one tank to another or from a tank to a net cage.

Counting of the Larval Fish

The scooping method commonly used in counting the number of larvae in the tank water follows the formula: number = (water volume of the tank/water volume of the container) x number of fish in the container. Tank water containing the larvae is scooped up at random using a container such as a beaker or a glass tube. The volume of water scooped is then measured and the number of fish counted. The calculation is done using the foregoing formula. Theoretically, the scooping of water from the tank must be made at random, but, in practice, it is hard to accomplish this for obvious reasons. Thus, the number of fish counted is taken as an estimation and by no means as a true value.

Survival Rate

The survival rate, i.e., the number of larvae harvested against the number stocked, differs by species and even within the same species. The difference in survival rates by species is discussed later. The different survival rates within species, however, may be noted in the red seabream (see Table 17). Data in this table indicate that the survival rate in the 0.5-t tank is higher than in larger tanks. The data further indicate that, on average, survival rates are lower in tank rearing than in net cage rearing.

Fish productivity or the number of fish produced in a given unit of space, differs by species and also within the same species, just like the survival rate. The specific differences in the productivity of most species are also given later. An example of productivity difference within the same species is the case of the red seabream (see Table 17). The number of the fish produced per tonne of tank water and the size of the tank are as follows: 11,000-57,000 fish/t in a 0.5-t tank, 8000-14,000 in a 10-t tank, 200-4000 in a 30-t tank, and 200-1300 in a 150-200-t tank.

These figures indicate that productivity decreases as tank size increases. This trend is also apparent when general tank management procedures and feeding practices are studied. In general, the smaller the tank the better is its management. The productivity in 100-5500-t net cages appears close to that of a 100-t tank, although one might expect it to be greater.

Critical Period

The survival rate of larval fish in a tank can be determined simply by counting the number of fish that have died. As a rule, the higher the mortality the lower the survival rate, however, a number of experiments and observations made on mortality rates have revealed the complexity of the issue. In general, mortality continues at the same

rate during the period of rearing and increases during a particular, i.e., critical, period or periods. Usually, there are two or three critical periods in most species. There are three critical periods observed in the red seabream, for example. The first critical period comes about 4 days after hatching, corresponding to the time of yolk absorption. However, the death rate is not high. The causes of death are inferior quality of eggs and other inherited factors, poor management of eggs, inability to feed, etc. The second period comes 12-17 days after hatching, corresponding to the time feeding starts. At this stage, the mortality rate is rather high. Causes of death are insufficient food, poor feeding, pollution of water, shortage of nutritive elements in the food, diseases, etc. The third period comes 20-25 days after hatching. Again, the mortality rate is rather high at this point and causes of death are unbalanced growth of the fish due to an insufficient supply of rotifer, short supply of copepods, inability of small individuals to adjust to the shift from live food to minced food, cannibalism, etc.

Transportation of the Larvae

Larval fish collected from the sea, e.g., yellowtail, need to be transported to the hatchery on shore. Larvae must also be transported when the fish are moved from tank to net cage or when rearing sites are duplicated. The shipping of the mojako larvae of the yellowtail is noted in the following section where larval grading by sizes is important to prevent cannibalism.

When being transported, the larval fish are placed in polyethylene bags containing water. The upper space of the bag is filled with oxygen or air. Often, a small amount of streptomycin or penicillin is added to the water. A number of these bags are then placed in a wooden or plastic tank filled with water or placed in a wooden or plastic box coated on the inside by heat insulation paint. These tanks or boxes are shipped by car or boat.

Sources: Fujita (1967, 1975), Kawamoto (1965, 1978), Red Seabream Larval Rearing Research Group (1977), Shigeno (1980), and Ueyanagi et al. (1973).

Diseases and Malformations

There are a number of studies on the diseases of marine fish, but most of them are concerned with subadult and adult fish. Compared to mature fish, there are few studies on the larval fish in the rearing stage, except perhaps in the case of the red seabream. The diseases of larval red seabream are noted later in this publication. Further studies on the diseases of larval fish, especially their relation to nutrition and feeding, are needed.

In many cases, the malformation or abnormal body structure in marine fish larvae under rearing mostly involves the vertebral column. Like diseases of marine fish, further studies are needed on the subject of malformation, especially on its relation to nutrition and feeding.

Sources: Arisono et al. (1977), Hoshina et al. (1965), Kubota (1980), and Red Seabream Larval Rearing Research Group (1977).

Mass Production of Live Food

The feeding of marine fish larvae in captivity starts with live food, usually rotifer. This supply of live food continues for a considerable length of time regardless of the species being reared. The types of live food used have been noted earlier. Some 10 artificially produced forms were mentioned. Mass production of live food has been conducted simultaneously with larval fish rearing, resulting in a highly developed technology. Table 6 shows the scope of live food rearing in terms of facilities used in comparison to those used in the rearing of larval fish. A description of the mass production of three kinds of live food, i.e., chlorella, rotifer, and tigriopus, follows. These are the most common types of live food used in Japan.

Chlorella

The cultivation of chlorella is usually done in an outdoor concrete tank with a capacity of 150-600 t. It is filled with seawater 1-2 m deep (Fig. 2c). Chlorella cultivation is based on the following procedures: (a) supply of carbon dioxide and inorganic fertilizers in the proper amounts, (b) adequate supply of lighting, (c) holding of the temperature at the proper levels, and (d) stirring of the water to keep an even density of chemical components and to prevent settling of the algae.

The chemical fertilizers usually supplied are ammonium sulphate (50-200 g/t), calcium phosphate (10-50 g/t), urea (5-25 g/t), and others. The concentration of each of these elements is adjusted according to the nature of seawater supplied to the tank, which in turn varies by localities and other factors. The range of optimum temperature for algal growth is 24-25°C.

The amount of chlorella produced, although varying according to several factors, has a range of 2-4 x 10^6 cells/mL within a 7-day period. It is also known that chlorella often disappear in water with temperatures of more than 30°C, but survive in temperatures of 20°C or less.

Rotifer

There are five types of rotifer depending on the food materials given and the process of rearing followed (see section on feeding). The food materials include chlorella, bakers' yeast, and bakers' yeast in which fatty acids have been assimilated. Rotifer may be reared using any of three methods: the thinning method practiced in a large tank, the thinning method used in a canvas cage, and the repeated stocking method in a small tank. Only the first method is described here because it is the one most often used. This method involves two procedures: feeding with chlorella and feeding with chlorella combined with bakers' yeast.

Feeding with Chlorella

Rotifer culture is carried out in an outdoor tank (Fig. 2b). First, seawater containing chlorella (10-20 million cells/mL) is placed in the tank, then rotifer is stocked into the water. When the water loses its green colour due to the thinning of chlorella consumed by the rotifer, about 25% of the water is drained out. From this water the rotifer is filtered out. The water drained out is then replaced by the same amount of seawater containing chlorella. An

Table 6. Tanks at the six fisheries experiment stations for the rearing of red seabream and for the cultivation of food organisms, rotifer, and chlorella.

Location of fisheries experiment station (prefecture)	Fish rearing tank capacity (t) x number A	Rotifer tank (t) B	Chlorella tank (t) C	A : B : C	Growing of rotifer[a]
Yamaguchi	50 x 6 = 300	158	460	1 : 0.5 : 1.5	ER
Nagasaki	100 x 3 = 300	160	340	1 : 0.5 : 1.1	MR
Kumamoto	100 x 1 = 100	180	625	1 : 1.8 : 6.3	GR
Kagoshima	60 x 4 = 240	120	330	1 : 0.5 : 1.4	ER
Oita	40 x 2 = 80	154	154	1 : 1.8 : 1.8	ER
Hiroshima	25 x 6 = 150	360	320	1 : 2.4 : 2.1	MR

[a] Growing of rotifer: ER = fed with yeast soaked in chlorella, MR = fed with both chlorella and yeast, and GR = fed with chlorella only (see section on feeding).

Source: Hirata et al. (1977).

example of actual rotifer production follows. The data are derived from the experiment conducted at the Nagasaki Prefecture Fisheries Experiment Station.

On 1 May, rotifer (71 pieces/mL) were stocked into an outdoor tank (5 x 7 x 1.4 m with water 1.2 m deep) filled with chlorella seawater. The rotifer cropped totaled 106×10^{10} pieces (31.8 kg) by 18 May. Actual production of rotifer (amount of final crop minus amount stocked) was estimated at 63×10^{9} pieces (18.9 kg) and the amount of chlorella seawater used was 319 t. During the 18-day operation the temperature of the water ranged from 15.4-20.2°C, the specific gravity was 23.8-24.8, and the pH value was 8.31-9.23.

Feeding with Chlorella Combined with Bakers' Yeast

Feeding with chlorella combined with bakers' yeast may be done in two ways: supplying chlorella at the beginning only or continuously. For example, rotifer production with chlorella supplied only at the beginning was used in an experiment conducted at the Kagoshima Prefecture Fisheries Experiment Station. The tank (7.5 x 4 x 2 m) used for the purpose is illustrated in Fig. 8. It should be noted that the tank is equipped with four filtration systems (C), air stones (B, B'), and an overflow tube (G) inside the tank. The bakers' yeast tank (H) and rotifer collection tank (J) are placed outside the main tank (F).

First, the tank was filled with chlorella seawater. Then, rotifer was stocked. After the chlorella had been consumed by the rotifer, yeast was supplied at the rate of 1 g/million of rotifer within a 24 hour time period. An overflow of water caused by a supply of additional seawater into the tank carried the rotifer into the collection tank (J) through the tube (G). The rotifer in the tank (J) were then picked out. The amount of additional water supply was regulated by checking the growth of the rotifer in the tank water. During the 28-day operation the rotifer collected amounted to 57×10^{9} pieces. The following account illustrates rotifer production where chlorella is continuously supplied. The data are based on the experiment conducted at the Nagasaki Prefecture Fisheries Experiment Station.

The experiment was conducted using seven outdoor tanks each with a capacity of 40 t and measuring 5.0 x 7.0 x 1.4 m with a water depth of 1.2 m (Fig. 2b). The tanks were exposed to sunlight and each tank was provided with 2-4 air stones through which compressed air passed, thus, agitating the surface of the water all day. Tank management consisted of the following steps:

- The tank was stocked with seawater containing chlorella (1-2 x 10/mL). The same kind of water replaced the tank water that was taken out for rotifer collection.
- Bakers' yeast was given twice a day during the whole course, the amount estimated being 1 g/million rotifer.
- Stocking of rotifer was done throughout the course, the number estimated being 10-100/mL.
- The collection of rotifer was done throughout the course by pumping out some water from which the organisms were sieved out. The amount of the water pumped out ranged from one-third to one-fifth of the total amount of water in the tank. The

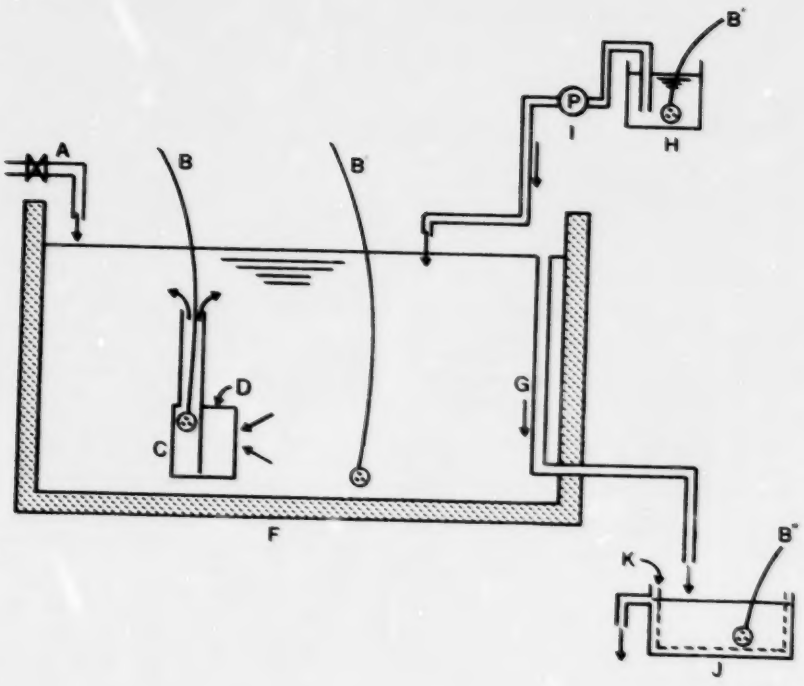

Fig. 8. Design of 60-t square tank for continuous growing of rotifer with facilities attached: A = seawater supply tub, B = compressed air tube ending in an air stone (B, two sets for each of four filtrators; B', four sets; B", two sets, and B"', three sets), C = filtrators (four sets), D = filter, F = main tank body, G = overflow tube, H = food tank (0.5 t), I = water flow pump, J = rotifer collection tank (0.8 t), and K = nylon cloth net (mesh size 76 μ). Note: The arrows indicate the direction of water flow (Hirata et al. 1977b with some modifications).

same amount of chlorella seawater replaced the drained tank water.

- If the tank water showed high turbidity, all the water was replaced.

Rotifer production in the Nagasaki experiment lasted 76 days (4 April-11 July). The water temperature was 15.4-27.3°C. The following results were obtained: rotifer stocked was 756.1×10^8 pieces, chlorella seawater used was 2808 t, the bakers' yeast supplied totaled 2459 kg, the number of rotifer harvested [(repeated collection + final collection) - stocking] was 3003×10^8 pieces and it was calculated that 1 kg of bakers' yeast produced 13.9×10^5 pieces of rotifer.

Tigriopus

Among planktonic copepods at least nine species have been reared in captivity. Of these species the Tigriopus japonicus has been the copepod that has been most commonly used as live food in marine fish larvae rearing. Because the procedures used for the mass production of these copepods do not differ much among these nine species, the cultivation of tigriopus is presented as an illustration of these procedures. The accounts given here are based on the experiments conducted at the Fukuoka Prefecture Fisheries Experiment Station and at the Nagasaki Prefecture Station.

The Fukuoka Station used a circular outdoor tank (8-m diameter with water 1.6-m deep) for the cultivation of tigriopus, which lasted for 30 days beginning 27 August. First, the seedlings collected from the sea were stocked in the tank filled with seawater. The water was aerated vigorously. Feeding consisted of dried yeast at 10 g/t of water every 2-3 days and formulated food at 10 g/t of water every 4-5 days. The multiplication of tigriopus (nauplius, copepodite, and adult) was observed to be about 1100 pieces/t of water on the 14th day, 850 on the 20th day, and 1400 on the 30th day.

The rearing of tigriopus combined with rotifer (Nagasaki Station) was conducted in a 200-t outdoor tank (7.0 x 5.0 x 1.4 m with water 1.2 m deep). The operation lasted for 72 days, from 8 May to 3 August. The tank water was vigorously aerated by six to eight air stones that made air bubbles continuously on the surface of the water. First, the tank was filled with chlorella seawater. Then, rotifer was stocked for 6 days at a concentration of 39.6/mL but no stocking was made of the tigriopus. Bakers' yeast was given twice a day throughout the course. The amount given was 1 g/million rotifer or a total of 694 kg.

The colour of the water in the tank changed from green to light brown to milky white to transparent and back to green. This indicated the growth of phytoplankton of various sorts. During the whole course the tank water was not renewed. The range of the water temperature was 18.8-30.7°C and specific gravity was 25.4-17.8.

The collection of tigriopus was done through an air-lifting tube, with one end covered by a minnow net (mesh size = 2 mm) and submerged in the tank. The tigriopus that flowed with the water were caught by a cloth from which the animalcules were scooped up. The collection started on 31 May and lasted for 65 days. The total amount of the tigriopus harvested weighed 43.2 kg.

Sources: Anraku (1979), Endo (1980), Fukusho et al. (1976a, b), Fukusho (1980), Hirata et al.(1977), Hirayama and Kusano (1972), Hirayama and Ogawa (1972), Kureha (1979), Kureha and Amagaya (1978), Kureha et al. (1978), Seikai (1979), Seikai et al. (1980), Shiroto (1975), Teramoto and Kawamori (1980), and Umebayashi (1961).

LARVAL REARING OF SELECTED SPECIES

This section deals with the larval rearing of each of the 12 species from 10 families of fish selected from among some 50 species on which spawn-taking and larval-rearing studies have been conducted. The selection of these 12 species was made at random. It must be noted that the discussion on each of the species may vary due to factors like the biological characteristics of the fish, concerned agencies, demand for larvae, and their economic value. However, following the basic principles in larval rearing presented earlier, the discussion of each species of fish will proceed along the following general lines: uses of fingerlings, brood fish and spawn taking, rearing of larvae, growth, production, and diseases and malformations. The order in which the species are discussed follows the taxonomical arrangement of the family to which each species belongs. Specific references are cited at the end of each section.

Scorpion Fish (Sebastiscus marmoratus) - Scorpaenidae

The scorpion fish, known as kasago in Japan, ranges from Hokkaido, southward along the Japanese islands to Taiwan, and from the two coasts of Korea down along the Asian continent to the East China Sea. The kasago usually dwells in rocky shore water. Being an ovoviviparous fish, it spawns in the winter to spring months.

One of the most common food fish in the country, the kasago attains a size of about 35 cm in the sea, which makes it a popular sport fish. The cultivation of the kasago in captivity is by no means common. However, the techniques used in the rearing of its larvae have been developed since the mid-1960s because (a) spawn taking is done in the winter season, (b) the kasago's brood fish are easily available, and (c) its sedentary habits in local waters cause no large-scale migratory movement.

The following accounts refer mainly to the work carried out in 1972 at the Sea-Farming Center in Oita Prefecture. According to the Japan Sea-Farming Association, 78,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The kasago fingerlings, grown to about 7 mm, were used for further rearing in captivity as well as for restocking to the sea.

Brood Fish and Spawn Taking

The brood fish, selected from commercial fishing catches, were reared in floating net cages for 1-5 years. They were grown to about 20 cm in length and to 230-500 g in weight. The brood fish were then transferred from the cage to a spawning tank. A total of 11 tanks,

each with a capacity of 200-t (except one tank with a 400-t capacity) were used for spawning and larval rearing. A net (3 x 3 x 3 m in size with a mesh size of 5.5 mm) was placed in each tank into which the brood fish were stocked. A total of 509 brood fish were placed in the nets of the 11 tanks and after 2-6 days 280 of the fish (55%) spawned in the net.

The hatchlings produced by the 280 brood fish (ovoviviparous) were estimated to reach a total of 11,850 x 10^3 (Table 7). The amount of larvae produced in each of the 11 tanks is shown in Table 7. The hatchlings measured 3.5-4.0 m long. The nets were removed from the tanks after spawning and the larvae were reared continuously in the tank from which they had originated.

Rearing of Larvae

Larval rearing was done in the 11 tanks for a period of 17-40 days (25 days on the average), from January to May. The water in the tanks where rearing lasted for more than 20 days was kept stagnant up to the 20th day after which 10% of the total amount of the water was replaced daily with new water. This amount gradually increased until it reached 50% of the total water capacity of the tank toward the end of the rearing period. Water temperature was kept at 13-14°C. To help the growth of chlorella, chemical fertilizers were supplied during the initial stages of larvae rearing, a period lasting from 3-4 days. The fertilizers included MG-1, $NaNO_3$ $NaHPO_4$, C1-32, and $NaSiO_3$.

Table 7. Record of the rearing of scorpion fish larvae in tanks, January-May 1972, Seto Inland Sea Fish-Farming Center. [The capacity of the tanks is 200 t for each except for tank no. 5 (400 t); initial size of larvae is 3.7 mm.]

Tank number	Initial number of larvae (10^3)	Number of larvae at harvest (10^3)	Survival rate (%)	Size of larvae at harvest (mm)	Rearing period (days)
1	1400	111	7.9	6.53	35
2	550	142	25.8	6.47-6.91	22-25
3	950	31	3.3	6.73	41
4	1150	64	5.6	6.86	39
5	1450	102	7.0	7.33	40
6	1250	0	0	--	22
7	900	5	0.6	5.94	17
8	1250	1	0.1	6.73	19
9	1200	0	0	--	14
10	1000	20	2.0	7.26	18
11	750	43	5.7	6.56	17
Total or average	11850	519	5.27	6.67	25.8

Source: Seto Inland Sea Fish-Farming Center (1973) with modifications.

Feeding

The main food item, rotifer, was given every day from the beginning to the end of the rearing period. A total of 4-14 x 10^7 of rotifer per tonne of water was used. Minced boiled eggs (15 g/200 t of water) were given from the 5th day but these were left uneaten by the larvae. Formulated food was also given but no conclusive data regarding it are available, except that the larvae were observed feeding in the later days of rearing.

As to the feeding activity of the larvae in the tank, the examination of the stomach contents of sampled specimens indicated that feeding gradually became active from dawn to midday and reached a peak at sunset. No feeding was observed during nighttime.

Growth

The growth of the larvae in the tanks differed from one tank to another. On the average, the growth rates of a 3.7-mm long hatchlings were as follows: 5th day, 4.2 mm; 10th day, 4.4 mm; 15th day, 5.3 mm; 20th day, 5.8 mm; 25th day, 6.2 mm; and 30th day, 6.7 mm.

As shown in Table 7 the final size of the larvae at harvest measured 6.67 mm on average. It should be noted that the larvae attaining the size of 6-7 mm are not large enough to be cultivated to marketable size. Thus, they are transferred to net cages for further rearing in the secondary phase.

Production

The survival rates of the larvae reared in the tanks varied greatly from tank to tank, i.e., from 0-25.8% (Table 7) making it hardly possible to reach a conclusion on the subject. However, the initial number of larvae in the 11 tanks (2.7-7 x 10^3 larvae/t of water), except tanks 1 and 4, showed a negative relation to the survival rates (0-25.8%) as well as to the amount of larvae at the end. These figures suggest that the lower the initial density of the larvae the higher is the survival rate.

Sources: Tsukahara (1962) and Seto Inland Sea Fish-Farming Center (1973).

Japanese Seabass (Lateolabrax japonicus) - Percichthyidae

Like the kasago, the Japanese seabass, known as suzuki in Japan, ranges from Hokkaido, southward along the Japanese islands to Taiwan, and from the two coasts of Korea down to the East China Sea along the Asian continent. The suzuki dwells in shallow coastal waters and moves to estuary brackish waters for spawning from fall to winter. The larval fish spawned usually enter into rivers where they stay in the spring and summer months before returning to the sea in the fall. This species grows to a length of 90 cm and is one of the most common food fish in Japan. It is also a popular sport fish. The larval rearing techniques used for this fish refer mainly to the experiments conducted at the Hiroshima Prefecture Fisheries Experiment Station. According to the Japan Sea-Farming Association, 335,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The fingerlings grown to about 30 mm in length are used for further rearing in captivity as well as for restocking to the sea.

Brood Fish and Spawn Taking

The brood fish, mostly selected from catches of fishing operations, are kept in floating net cages (5 x 5 x 5 m). The mature brood fish are taken from the net and transferred to circular spawning tanks (75-t capacity) where they lay eggs naturally or by induction of a hormonal injection. The following records of spawn taking were made during 3 years of experimentation (1976-78).

On 13 December 1976, 10 males and three females (61, 64, and 66 cm total length) were placed in the tank. These spawned 820,000 eggs on the following day or 273,000 eggs per female. The next year, on 13 December 1977, five males and a female (82 cm) were placed in the tank. These spawned 796,000 eggs on the following day. On 10 January 1978, one female (61 cm) was placed in the tank after being injected with hormones. It spawned 199,300 eggs the next day. Each of the three lots of spawned eggs were kept in a cloth net (75 cm in diameter, 70 cm deep) and placed in tank water warmed by heated air.

Rearing of Larvae

Larval rearing was conducted in two phases: the primary phase (1976-78) and the secondary phase (1977-78). The results are shown in Tables 8 and 9, respectively. In the primary phase, a total of 10 plastic indoor tanks (each 500-L capacity) were used. A specified number of eggs were stocked in each tank. At the same time about 200 eggs were placed in a glass beaker with a 3-L capacity. From the hatching rate of 200 eggs, the number of larvae hatched in each of the rearing tanks was estimated.

The tank was covered on its four lateral sides by a dark film to prevent the penetration of light. However, the tank itself was lighted by two 20-W fluorescent electric lamps placed 40 cm over the tank. These lamps were turned on from 07:00 hours to 20:00 hours. Seven of the 10 tanks were supplied with chlorella water 3-7 days after the eggs hatched. The amount of chlorella supplied was 5-12 L/day for a period of 33-36 days (Table 8). Beginning from the 7th day after the eggs hatched until the 30th day, the tank water was changed at a rate of 100-200 mL/min. This rate was increased to 300-500 mL/min from the 31st day to the end of the rearing period. The water was kept at temperatures listed in Table 8 using a 150-W glass-tube heater placed in the tank. The bottom of the tank was cleaned by a siphon that picked up dead fish and debris. The cleaning started 7 days after the eggs hatched.

The secondary-phase rearing was conducted in four floating net cages. The cages used for the first 40 days were 2.7 x 2.7 x 2.7 m in size with a net mesh size of 1 mm. The upper edges on four sides of the cage were covered by a polysheet 50 cm deep to keep the larvae from escaping. The net cages used for the next 40 days were 3 x 3 x 3 m in size with a net mesh size of 2.3 mm. A 150-W electric light tube was set over the net cages and turned on from 17:00 hours to 22:00 hours to attract planktonic organisms into the cage.

Table 8. Data from the experiment on the rearing of Japanese seabass larvae conducted in the 10 plastic tanks of 500-L capacity showing the stocking, water management, feeding, and the harvest; period of feeding denoted by the days after the start of rearing (see text).

Tank no. (day/month/year)	Hatchlings stocked		Rearing (days)	Water temp. (°C)	Chlorella supplied (days)	Feeding				Harvest of fingerlings		
						Rotifer		Copepods				
	No.	Average length (mm)				No. (L/day)	Period	No. (L/day)	Period	No.	Average length (mm)	Survival rate (%)
1 (19/12/76)	8470	3.9	48	11.6-16.4	35	6800	5-33	196	16-47	2905	14.5	34.3
2 (19/12/76)	8470	3.9	48	11.6-16.4	35	6800	5-33	196	16-47	4598	14.5	54.3
3 (19/12/76)	8470	3.9	47	11.6-16.4	35	6800	5-33	196	16-47	2572	15.9	30.3
4 (19/12/76)	8470	3.9	48	11.8-18.8	0	6800	5-33	196	16-47	1258	16.5	14.9
5 (19/12/76)	8470	3.9	48	11.8-18.8	0	6800	5-33	196	16-47	1639	14.9	19.4
6 (19/12/76)	8470	3.9	47	11.8-18.8	0	6800	5-33	196	16-47	2013	15.9	23.8
1 (19/12/77)	5700	4.2	43	13.0-19.1	36	5050	5-42	188	17-42	2433	14.1	42.7
2 (19/12/77)	5700	4.2	43	13.0-19.1	36	5050	5-42	188	17-42	1561	14.9	27.4
1 (16/01/78)	9950	4.0	43	12.5-18.0	33	4880	6-42	153	21-42	5791	12.7	58.2
2 (16/01/78)	9950	4.0	43	12.5-18.0	33	4880	6-42	153	21-42	3340	13.1	33.6

Source: Fushimi (1979) with modifications.

Table 9. Record of the rearing of Japanese seabass juveniles in four floating net cages showing stocking and harvesting. The fingerlings stocked were derived from the rearings in the tanks (Table 8). (For the cages used and feeding see text.)

Cage no. (day/month/year)	Fingerlings stocked		Rearing (days)	Seawater temp. (°C)	Harvest of the young			Survival rate of hatchlings (%)
	No.	Average length (mm)			No.	Average length (mm)	Survival rate (%)	
1 (5/2/77)	9142	14.5	75	8.2-12.2	4009	28.3	43.8	12.8
2 (5/2/77)	6323	16.5	75	8.2-12.2	2869	37.5	45.4	13.4
1 (31/1/78)	3994	14.7	101	9.7-14.8	1606	26.8	40.2	14.1
2 (28/2/78)	9131	13.1	73	9.7-14.8	3664	31.1	40.1	18.4

Source: Fushimi (1979) with modifications.

Feeding

The data on food, i.e., the amount supplied and the duration it was supplied, are shown in Table 8. The rotifer were cultured by chlorella and copepods collected from the sea and attracted by artificial lighting. The larvae entering the free swimming stage started feeding 5-6 days after hatching. Minced sandlance and mysis were fed to the larvae in the net cages every day at 11:00 hours and at 15:00 hours. The larvae in the cage also consumed planktonic organisms attracted by the light.

Growth

The growth of the larvae in each of the 10 tanks showed a gradual increase following a linear pattern. A hatchling initially measuring 4 mm showed the following growth rates: 10th day, 5.8 mm; 20th day, 8.2 mm; and 30th day, 14.0 mm.

A slight difference was noted between the growth rates of the larvae kept in the tank where chlorella was supplied (1.5 mm longer) and the tanks not supplied with chlorella. However, at the end of the rearing stage, growth rates between the two lots showed no difference.

The survival rates of the two types of larvae reared in the 10 tanks, unlike their growth rates, showed a significant difference. The larvae reared in the chlorella-supplied water showed a survival rate of 27-58% (or an average of 40%); those in the water without chlorella showed a rate of 15-24% (or an average of 19.3%).

A decrease in number due to death, which determines the survival rates, was witnessed twice during the course, i.e., two critical periods. The first one occurred on the 10th day after hatching and the second one around the 40th day. The mortality rates, although varied by the tanks, were estimated at 64.8-95.7% in the first period and 10-15% in the second period. The examination of the samples indicated that the cause of death in the first period was insufficient feeding. In the second period, death was caused by abnormal body structure.

The growth of larval fish reared in net cages also showed a normal pattern in each cage starting from 13-16 mm and ending with 27-37 mm, with some difference among the four lots. The survival rates of the larvae reared in net cages was 40-45% at the end of the rearing period, again with some differences among the four lots in the four cages.

The survival rate of the larvae during the whole course of rearing (125-150 days) was estimated at 12.8-18.4%, a rather high reading compared to other marine fish larvae.

Sources: Fushimi (1979) and Suzuki and Hioki (1979).

Horse Mackerel (Trecharus japonicus) - Carangidae

The horse mackerel, called maaji in Japan, ranges from southern Hokkaido along the Japanese islands down to the Ryukyu Islands, and from Peter the Great Bay down to the two coasts of Korea along the Asiatic continent. The species dwells in the bottom layers of coastal waters 50-90 m deep. There are two types of maaji - the dark coloured

kuroaji found in offshore waters and the yellowish kiaji frequenting inshore waters. The two belong to the same species. They grow to a length of 30 cm and weigh 550 g by the 4th year. Spawning is observed from March to May with the peak occurring in April.

The maaji is a very common food in Japan and fetches a high price at the market. The cultivation of maaji, however, has only been done recently, i.e., 1970s. Thus, the techniques used in its cultivation have not yet been well developed when compared to those used for the seabream, yellowtail, or tiger puffer. The explanations of the processes of larval rearing that follow are drawn mainly from the experiments conducted at the Nagasaki Prefecture Fisheries Experiment Station. According to the Japan Sea-Farming Association, 118,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The larval fish grown to 6-9 cm long are further cultivated in net cages. But, so far, they have not been used for restocking to the sea.

Brood Fish and Spawn Taking

The brood fish adopted for spawn taking depend on the fish reared, not on natural spawners. The fish (20-30 cm) are selected from the catches of fishing operations and cultured for 2-4 years. These fish are then treated with inducement hormones for spawning in April or May. The procedures for spawn taking through hormone injections that were practiced at two fisheries stations follow.

At the Kochi Prefecture Station a total of 40 fish, males and females, were injected with gonadotropin (200 MU dissolved in 0.6% salt solution) amounting to 0.5 mL/fish. The treated fish were placed in a 10-t tank. These fish spawned in the tank 35-37 hours after the injection and the total number of eggs spawned was estimated at 120,000. The temperature of the tank water was kept at 20-21°C. The eggs deposited were inseminated in the tank water and they developed normally. About 40 hours after insemination the eggs hatched.

At the Nagasaki Station, a total of 203 male and female fish with an average length of 38 cm were kept in net cages for about 12 months. The fish were fed formulated food and minced fish meat. By checking the gonad development of selected specimens, the gonad index $[(GW/FL^3) \times 10^4]$ reached 10.38 ± 5.31 to 11.69 ± 2.47 in females and 7.81 ± 2.38 to 8.19 ± 2.90 in males. These fish were treated with hormone injections on 1-7 May. The hormone was prepared from the hypophysis of a chinese carp (Hypophthalmichthys molitrix) that was dehydrated by acetone and diluted into a physiological salt solution. The injection was given to mature fish that were separated into three groups: A, B, and C (Table 10).

Immediately after the injection the brood fish were transferred to a spawning tank (3 x 4 x 1.2 m with water 1.0 m deep). The eggs spawned in the tank water were collected through an outlet with a collecting net over a period of 24 hours. Egg collection was also done by scooping with a dip net. Dead eggs deposited on the bottom were collected by a siphon. The final number of live eggs (floating) is shown in Table 10. The hatching of these eggs was traced in the larval rearing tanks into which live eggs were stocked. Hatching of the eggs in each lot is shown in the same table. It should be pointed

Table 10. Record of spawn taking by hormone injection on horse mackerel conducted at the Nagasaki Prefecture Fisheries Experiment Station in 1980 showing brood fish used, injection of hypophysis, and eggs collected in course and obtained at harvest and hatching rate.

Group	Brood fish (male and female)			Injection		Eggs collected			Eggs obtained		
	No.	Fork length (mm)	Weight (g)	Date/time	Dosage (mg/kg)	Date/time	Total (g)	Floating (g)	Weight (g)	No. (10^5)	Hatching rate (%)
A	36	29.0 ± 1.7	371.2 ± 87.6	1 May 14:00 hrs	6	3 May 1:00-2:00 hrs	677	452	206	62	25.5
B	15	28.5 ± 1.4	342.0 ± 65.4	7 May 14:00 hrs	3	9 May 1:00 hrs	400	220	80	24	29.4
C	15	28.5 ± 1.4	342.0 ± 65.4	7 May 14:00 hrs	1.5	9 May 1:00 hrs	391	325	65	20	29.4

Source: Seikai and Kitajima (1980) with modifications.

out that eggs were laid 35-37 hours after the hormone injections and the eggs hatched about 40 hours after natural insemination in the tank water.

Rearing of Larvae

The following is a summary of the larval rearing of maaji experimented on at Kochi Station. About 20,000 hatchlings were reared in the tank for 53 days starting from 18 April. These were then transferred to floating net cages in which they were reared for 35 days ending on 17 July. The feeding procedures were as follows: rotifer was given 4 days after hatching until the 40th day; daphnia, from the 19th to the 53rd day; sardine larvae, from the 32nd to the 55th day; and minced meat, from the 46th day until end of the rearing period. The growth of the larvae (for hatchlings 2.3-2.5 mm in length) during the entire 90-day rearing period was: 10th day, 3.2 mm; 20th day, 6.4 mm; 30th day, 14.6 mm; 54th day, 40.2 mm; 60th day, 52.4 mm; and by the 90th day (end of rearing period), the length was 97.8 mm. The survival rates in the same 90-day rearing period were as follows: 30th day, 26.2%; 40th day, 22.8%; 60th day, 18.4%; 75th day, 18.2%; and for the 90th day (end of rearing period), the survival rate was 18.0%. The rearing of maaji done at the Nagasaki Station follows and is supplemented by more detailed accounts in Table 11.

The eggs obtained from the group A brood fish (Table 10) were placed in a 40-t outdoor tank (7 x 5 x 1.4 m with water 0.8 m deep) in which the eggs hatched. Two dark curtains (each with a 70% light shading capacity) were placed over the tank and the water was aerated by 12 air stones. The water was kept stagnant for the first 3 days after which it was replaced by new water in gradually increasing amounts. The eggs derived from the B and C groups of brood fish were placed together (B+C) in a 10-t indoor tank (3 x 4 x 1.2 m with water 0.85 m deep). A dark curtain was placed over this tank and water was aerated by six air stones and treated in a way similar to the water in the 40-t tank.

Feeding

Seven kinds of food were supplied. Details regarding this food are shown in Table 11. The rotifer was cultured by fatty bakers' yeast mixed with chlorella, whereas the artemia was cultured by bakers' yeast alone. Tigriopus was collected together with the cultivated rotifer, and minced fish was composed of four parts sandlance and one part mysis.

Growth

The growth of the larvae in the two tanks, i.e., 40 t and 10 t, was observed to follow nearly the same trend. A hatchling (2.5 mm in length on average) grew to 5 mm 20 days after hatching, 12 mm 30 days after, 23 mm 40 days after, and 28 mm after 45 days or at the end of the rearing period.

Production

The eggs of the brood fish in group A that were stocked in the 40-t tank hatched on 5 May. These numbered about 15.8×10^4 but half of them were abnormal, i.e., their bodies were bent, and, thus, they did not survive. The number of abnormal individuals increased day after day, and by the 4th day after hatching the total number of live

Table 11. Rearing of horse mackerel larvae in tanks conducted at the Nagasaki Prefecture Fisheries Experiment Station in 1980 showing the details of the rearing process. Groups A and B+C correspond to the same brood fish in Table 10.

Food items	Total amount given (g)	Duration of feeding
Group A [a]		
Rotifer	36.8×10^8	25 days from 7 May
Copepods	180	15 days from 18 May
Tigriopus	2580	16 days from 29 May
Artemia	3310	25 days from 20 May
Striped knifejaw eggs	1960	16 days from 28 May
Formulated food	450	4 days from 12 June
Minced fish	19500	8 days from 12 June
Group B+C [b]		
Rotifer	9.4×10^8	20 days from 13 May
Copepods	170	5 days from 28 May
Tigriopus	3700	20 days from 30 May
Artemia	3100	23 days from 20 May
Striped knifejaw eggs	3150	22 days from 29 May
Formulated food	450	4 days from 9 June
Minced fish	11400	9 days from 12 June

[a] In group A, the duration of rearing was 47 days from 4 May, a 40-t outdoor tank was used, and the number of hatchlings was 15.8×10^4 at a water temperature of 16.2-22.8°C. At harvest there were 10,000 fingerlings ranging in size from 27.97 ± 4.50 mm with a survival rate of 6.3%.

[b] In group B+C, the duration of rearing was 43 days from 10 May, a 10-t indoor tank was used, and the number of hatchlings was ca 12.8×10^4 at a water temperature of 17.4-22.1°C. At harvest there were 8000 fingerlings ranging in size from 28.96 ± 3.46 mm with a survival rate of 6.3%.

Source: Seikai and Kitajima (1980).

fish decreased to 7.5×10^4. Afterward, there were fewer abnormal individuals found until the end of the rearing period or 47 days after hatching. At that point, about 10,000 or so individuals were counted. The survival rate was calculated at 6.3% and the size attained by the fish was about 28 mm.

The eggs of group B+C hatched on 11 May numbered about 12.8×10^4. All of them developed abnormally. But, from the 12th day after hatching many of the larvae lost their swimming ability and were carried to the tank walls and died. By the 19th day after hatching nearly one-half of the larvae had died. At the end of the rearing period (43 days) the larvae had grown to the size of 29 mm, but the survival rate was only 0.25%.

The larvae that survived in the tanks (both groups A and B+C), a total of 18,000, were transferred to a floating net cage (3 x 3 x 3 m) and reared for about 17 days. They were fed minced sandlance amounting to 413.8 kg. In other words, the daily feeding amounted to 100% of the fish's body weight. By the end of the rearing period, the fish had grown to about 70 mm. The survival rate was nearly 100%, which means that only 20 or 30 fish died in the cage just after stocking.

Malformation

In addition to the bent-body abnormality found among the fish in group A, a condition that caused high mortality, a few individuals reared in the net cage also showed centrum fusion. However, these individuals were few and their number negligible.

Sources: Ochiai et al. (1980), Sato and Mori (1980), and Seikai and Kitajima (1980).

Yellowtail (Seriola quinqueradiata) - Carangidae

The yellowtail is a migratory fish that ranges from Hokkaido down along the Japanese islands and the eastern coast of Korea to Taiwan. The species dwells in coastal surface water usually in schools and does not enter deep into inland seas. The Japanese have different names for the yellowtail depending on the size of of the fish: buri (65 cm or more), warasa (30-65 cm), hamachi (20-30 cm), wakanago (10-20 cm), and mojako (10 cm or less). These names are apparently related to the stages of cultivation. The larvae and juveniles (the mojako stage) are used for seedlings. Cultivation in net cages is done when the fish is in the hamachi stage. The buri fish grows to about 1.8 m long in the sea by 8 years of age.

The yellowtail is a popular food fish in Japan and this popularity has generated much of its cultivation. In fact, the production of the species through cultivation amounting to some 150,000 t/year at present surpasses the catches of fishing operations. The other remarkable fact is that the fingerlings used for cage culture are derived mostly from the mojako larvae collected from the sea. The larvae obtained artificially play a minor role. Statistics indicate that the number of fingerlings used in a year amounts to 75 million. Of this number, 230,000 are produced in captivity.

Artificial spawn taking and larval rearing up to the fingerling stage have been experimented on by a number of fisheries agencies. The experiments conducted from 1950-60 succeeded in hatching eggs derived from brood fish caught in the sea. In 1965, inducement by hormone injections was successfully accomplished. In the years 1967-70, spawn taking was made from brood fish cultured in net cages, and, since 1978, spawn taking of the cultured fish in either net cages or tanks has been the subject of a number of experiments.

The following accounts are divided into two: (a) the rearing of the mojako larvae and (b) artificial spawn taking and larval rearing. The first part was drawn mainly from Shigeno's work (1980) and the second part mainly from Fujita's (1980).

Uses of Fingerlings

The fingerlings of the yellowtail, whether derived from the mojako larvae or reared artificially, are used for further cultivation in net cages but not for restocking to the sea.

Rearing of the Mojako Larvae

Ecology of the Larvae

The spawning behaviour of the yellowtail in the sea is not known precisely. The development of its eggs to larvae that reach 10 mm is also not known because it has been observed only in laboratories.

The mojako larvae appear from April to June along the shores of both the Pacific Ocean and the Sea of Japan. The Kuroshio warm current runs northward along the Pacific coast and the Tsushima current (a branch of the Kuroshio) moves northward from the western coast of Kyushu along the Sea of Japan coast. The appearance of the mojako larvae has been noted to extend northward to the Sagami Bay (Latitude 35°) along the Pacific coast and to the Wakasa Bay (Latitude 36°) along the Sea of Japan coast. In the southern end of the country the larvae probably appear in the waters of the northern Ryukyu Islands. However, they are never seen in the Seto Inland-Sea, the centre of yellowtail culture in Japan, nor in other inlets or small bays.

The larvae usually swim below or around drifting seaweeds. Their density is higher in the waters along the Pacific coast than in the Sea of Japan. The size of the larvae varies by localities and seasons. They range from 10-170 mm long, although those that are 30-70 mm in length are more abundant. In southern Kyushu, it was observed that the larvae measured 10 mm in early March, 20-30 mm in late March, and 170 mm in mid-May.

The feeding habits of the larvae (Fig. 9) have an important bearing on their food supply during the rearing period. The major food item of the smallest larvae (10 mm) is copepod. A slight amount of sardine eggs is added at the next stage. When they reach 30 mm in length, the larvae feed on other fish, and the amount of fish food increases gradually along with the larvae's growth. The larvae that have grown to 120 mm long become strictly piscivorous and no longer include copepods in their diet. Food eaten by the mojako larvae (10-170 mm) consist of copepods (46%), their own larvae (12.5%), euphasia, sardine eggs, chaetognaths, larval carangoid fish, and others. The cannibalism lasts from the time the larvae are 50 mm long until they are 150 mm long. The peak occurs around the time they are 100 mm long. The larvae preyed on are about half the length of the predating larvae. It should be noted that the rather high incidence of cannibalism found in the yellowtail larvae has an important bearing on their rearing in captivity.

Collection of the Larvae

Catching yellowtail larvae is regulated by law at present and a special licence is issued by fisheries agencies. The fishing gear used is a circling net with a float line 50 m long and a 40-m sink line. The gear is operated by a 2-7-t vessel equipped with live fish tanks. The larvae trapped in the net are kept in live tanks and graded into two to three lots by sizes. Each lot is placed in a

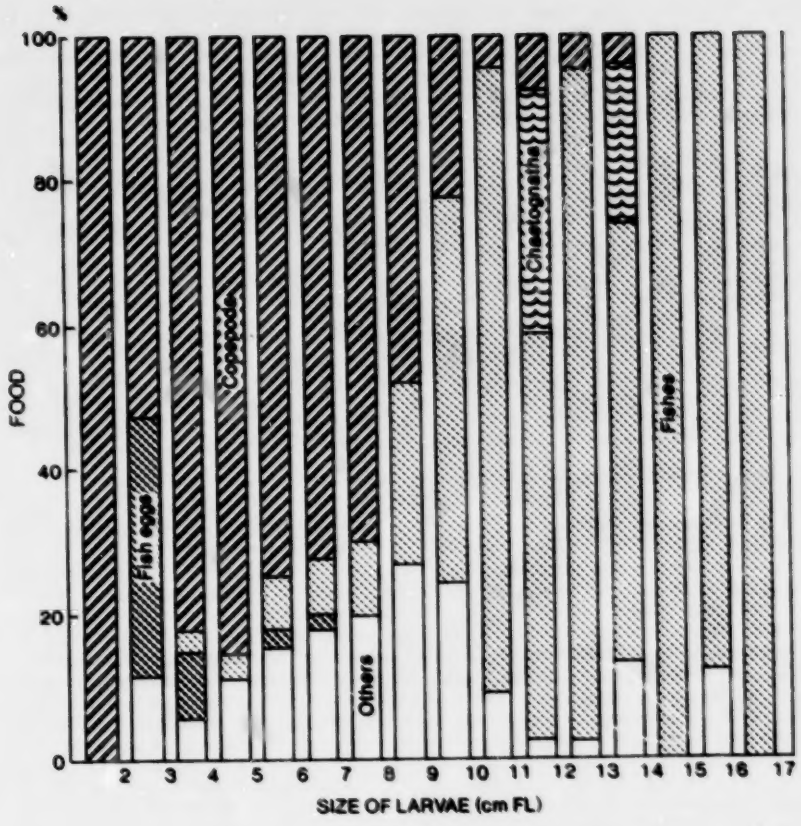

Fig. 9. Food eaten by yellowtail larvae and young in the sea. The weight of food items is expressed in percentages for given sizes of larvae examined on a total of 3158 specimens (Shigeno 1980 with modifications).

separate tank to prevent cannibalism. It has been shown that 2.75-16.6-cm larvae that were collected but kept in one live tank decreased in number by 11.6% during a 5-hour navigation to the shore. The grading of the larvae by sizes is accomplished by passing the fish through nets of different mesh sizes.

Rearing of Larvae

As noted earlier, among the mojako larvae collected in the sea there is an abundance of individuals measuring 30-70 mm. These larvae are reared in floating net cages until they reach 50-100 mm in length and are used as seedlings for further rearing in cages until the marketable size (200-300 mm) is reached.

The fishing grounds for the mojako larvae are restricted to the deeper waters of the outer seas, whereas the net cage cultivation is practiced in the inland sea coastal areas. Thus, the collected larvae must be carried from the fishing grounds to the cultivation sites. Even when the rearing sites are located on the coast facing the fishing grounds, the larvae must still be transported.

The transport or shipping of the larvae is done by vessel or trucks. Containers come in various sizes and designs, and, although grading of the larvae according to sizes is done to prevent cannibalism, it has also been found that the larvae that are 10 mm long or longer are better able to survive handling.

Facilities Used

The mojako larvae are usually reared in floating net cages with an area of 2-5 m^2 and a depth of 1-3 m. These are set up in inshore waters. The mesh size of the net often starts at 9 mm or less and it is increased as the larvae grow. In most cases, the cages are equipped with artificial lighting, which attracts planktonic organisms into the net and stimulates feeding activity at night.

Feeding

Evaluation of the food for the rearing of mojako larvae was the subject of the following experiment. The larvae (23-35 mm) collected from the sea were stocked in five glass containers (each measuring 60 x 30 x 36 cm). Thirty larvae were placed in each container. These larvae were reared for 17 days with each container of larvae receiving a different kind of food. The food given and the survival rates of the larvae that received this food were as follows: live copepods, 67%; artemia nauplii, 36%; frozen shrimp, 50%; minced sandlance, 27%; and horse mackerel, 27%. The highest survival rate shown by larvae fed with copepods reflects the feeding habits of the larvae in its natural environment (Fig. 9).

A general trend observed in the feeding behaviour of larvae in net cages was that when the food was restricted to minced fish meat the smaller larvae showed higher mortality. They also grew to be weak fish even though they attained a size of more than 10 cm long. In contrast, the larvae that were 10 cm or longer survived and were in good health even though they were fed minced fish alone. This fact corresponds well to the feeding habits of the larvae in the sea (Fig. 9).

Artificial Spawn Taking and Larval Rearing

Since 1968, artificial spawn taking and larval rearing of the mojako larval have been practiced. Thus, the biological techniques required for these activities have been developed. Fisheries researchers and officials are anxious to develop further these techniques so that in the near future reared larvae in captivity will replace natural mojako.

Brood Fish and Spawn Taking

The yellowtail matures in 3 full years and attains a size of 65-70 cm and a weight of 5 kg or more. The number of eggs carried by a mature female weighing 4-5 kg amounts to 0.5 million, a 6-8 kg female fish carries 1 million eggs, and a 9-kg female, 1.5 million.

Spawning starts in February-March in the northern seas of the Ryukyu Islands. The spawning activity continues northward until June. The eggs are obtained by stripping the mature females selected from catches of fishing operations. However, successful spawn taking depends on the hormone injection given to females from these catches or to those kept in cages after being caught.

Synahorin is used for the injection and the dosage is 4 RU/kg of fish. The injection is given in the dorsal muscles. The ovarian eggs develop to full maturation 48-72 hours after the injection, after which they are ready for stripping. Insemination by the dry method is made in a glass bowl and the fertilized eggs are placed in a spoon net and washed with seawater. The number of eggs obtained by stripping from a hormone-treated fish usually amounts to 50% of the total number of ovarian eggs, i.e., 150,000-200,000 eggs from a 4-5-kg fish and 150,000-500,000 eggs from a 6-8-kg fish. The inseminated eggs are placed in a large plastic or glass container filled with seawater in which the pelagic eggs float. Those eggs that develop abnormally sink to the bottom and are removed by a siphon. The floating live eggs are then transferred to a hatching tank.

The hatching tank often used is a square concrete tank (3 x 3 x 1 m) that has aeration and temperature control systems. The eggs hatch 50 hours after insemination in water at 21-24°C, 70 hours at 18-21°C (optimum), and 90 hours at 15-18°C. The hatchlings measure about 3.5 mm long.

Rearing of Larvae

Larval rearing is usually done in the same tank in which the eggs hatched. Feeding starts 72-90 hours (3-4 days) after hatching. Figure 10 illustrates the schedule of feeding and larval growth. As this figure shows, the growth of the larvae follows a linear pattern with a marked incline around 30 days after hatching. This coincides with the supply of fish larvae and fish meat. The larvae that have

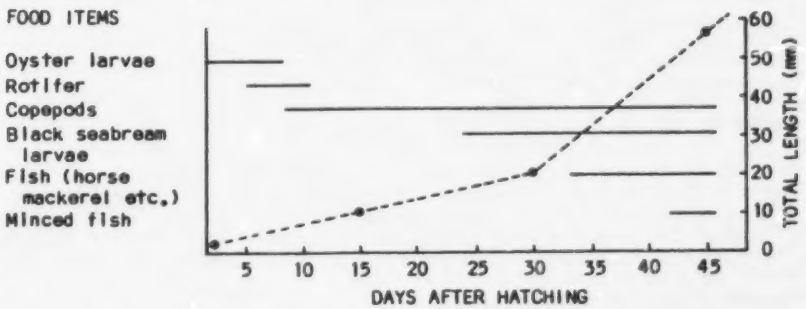

Fig. 10. Food given to yellowtail larvae reared in captivity showing the duration of feeding for each food item and approximate growth rate during rearing (Aquaculture Data-Book Editorial Committee 1976).

grown to 60 mm or so in the tank are grown further to reach seedling size. The second-phase rearing is done in net cages similar to that used for the mojako larvae (see previous section).

Sources: Aquaculture Data-Book (1977), Fujita (1980), Fukusho (1981), Japan Sea-Farming Association (1981), Miki and Takashiba (1960), Ninomisawa and Sakai (1969), Seto Inland Sea Fish-Farming Center (1978), Shigeno (1959, 1960, 1980), and Umeda and Ochiai (1971).

Red Seabream (Pagrus major) - Sparidae

The red seabream, known as madai in Japan, ranges from Hokkaido down along the Japanese islands to Taiwan and from Peter the Great Bay southward to the northeastern part of the South China Sea. The usual habitat of this species is rocky bottom water 30-150 m deep. The madai grows to nearly 1 m in length and has a life span of 20 years. However, the fish sold at the marketplace measure 20-40 cm, weigh 2-4 kg, and are only 4-7 years old. One of the most popular food fish in the country, because of its delicate flavour and its attractive shape and colour, the madai is called the king of marine fish and is sold at a high price in the marketplace. Given these characteristics, the cultivation of the red seabream has become very popular and its production through cultivation amounts to 14,000 t/year ranking second only to the yellowtail (15,000 t/year). According to the Japan Sea-Farming Association, 22,623,000 seedlings were produced in Japan in 1980.

The rearing of marine fish larvae in Japan is represented by the techniques used for the red seabream as the artificial hatching of the eggs of this species was successfully developed as early as 1887. The rearing of red seabream larvae into fingerlings was achieved in the mid-1950s. Since then the production of fingerlings has increased from year to year and the adoption of rotifer for feeding (1965) brought about the mass production of the larvae.

Among all the species of marine fish in Japan, it is apparent that the madai has been the subject of the greatest number of studies and experiments on spawn taking and larval rearing. The accounts that follow refer mainly to the work done by the Red Seabream Larval Rearing Research Group (1977) and others (see sources listed at the end of this section).

Uses of Fingerlings

The fingerlings of the red seabream are used as seedlings for the cultivation of marketable size fish in floating net cages. Also, a large number of these fingerlings is restocked to the sea to increase the population in a given area. So far, only with the red seabream have successful results been obtained in this respect.

Brood Fish and Spawn Taking

The brood fish from which eggs are usually taken are 3-4 years of age (1-2 kg in weight), but fish up to 8 years of age can also be used. Fingerlings grown to brood fish come either from natural sources or artificial ones. The brood fish selected from catches of

fishing operations are not suited for spawn taking because these fish are not accustomed to the spawning tank and show extremely low activity in egg depositing. Moreover, the eggs stripped from this kind of fish have a much lower hatching rate compared to those eggs derived from reared brood fish.

Keeping of Brood Fish

The brood fish are usually kept in floating net cages. The mature fish are moved to the spawn-taking tank and, after spawning is finished, they are returned to the net cages. A net cage measures about 3 x 3 x 3 m and the stocking rate of brood fish is estimated at 5-7 kg/t of water. The details of brood fish keeping are shown in Table 12.

The food given to the fish in net cages includes frozen fish or formulated food, never live food. Scomber, anchovy, sandlance, etc. are minced before being fed to the fish. Minced fish is also mixed with formulated food. Materials must be fresh and uneaten food items removed.

The temperature of the water, another factor that determines the health of the fish and the proper development of its ovary, ranges from 7-30°C within the year. The low temperatures during the winter months, e.g., 5-7°C, result in high mortality rates especially when the water in the cage is moving.

Spawning

The brood fish in net cages mature as the water temperature rises to 14-18°C (April-May). At this point, the maturation of the fish is checked. Among females, maturation is manifested by a swollen belly due to the inflation of the ovary. Among males, nuptial coloration (darkening from head to belly) or the amount of sperm discharged indicates maturation. The gonad index (IR = (GW/BW-GW) x 10^2) for both male and female) reads 2-4 from February to March, 7-8 from April to May, and decreases after June. These readings are found to be nearly equal to those for fish in the sea. Temperature is the major factor in inducing gonadal maturation. An experiment has also shown that a rise in temperature has brought about spawning (Fig.11).

The mature fish are transferred to the spawn-taking tank (Fig. 3) or to an ordinary culture tank. The size of the tank and the number of brood fish stocked are shown in Table 13, which presents actual data obtained by different stations. The number of eggs obtained are eventually affected by numerous factors making it almost impossible to understand the complex relation between the two subjects. However, assuming that other factors remain constant, it has generally been accepted that a 50-t tank is the most effective one for spawning.

The fertilized eggs float on the surface of the tank water and the dead eggs sink to the bottom. It has been observed that the number of floating eggs is higher (80%) in the middle portion of the spawning activity than at the beginning and the end. The eggs are mostly discharged during sunset hours. Thus, they are collected between 19:00 and 20:00 hours and not earlier or later to avoid excessive stirring of the tank water. The collected eggs are moved to a hatching or an incubation tank (Fig. 4c). In some cases they are stocked directly into the larval rearing tank.

Table 12. Details of the cultivation of the red seabream brood fish by the nine prefecture fisheries experiment stations.

Prefecture	Age of fish (year)	Derivation	Weight (kg)	Facilities (tank on land; floating cage on sea)	Food given to brood fish	Temperature of water (°C)
Kagoshima	3	Natural fry	1-2	1000-t tank	Pellet	14-29
Miyazaki	4	Cultured fry	1-2	Floating cage (5 x 5 x 3 m)	Pellet	14-28
Kumamoto	4-8	Both natural and cultured fry	1-5	100-t tank	Pellet	13-26
Oita	6-8	Adult fish from sea or natural fry	3-5	Floating cage (3 x 3 x 3 m)	Formulated powder with fish	12-26
Nagasaki	4	Cultured fry	1.5-2	Floating cage (5 x 5 x 5 m)	Fish	12-30
Saga	3-4	Natural fry	1-2	Floating cage (5 x 5 x 5 m)	Pellet and fish	10-28
Fukuoka	4-6	Natural fry	2	5-t tank	Pellet	7-20
Yamaguchi	4-5	Natural fry	1-2	Floating cage (4 x 4 x 4 m)	Fish	9-28
Hiroshima	7-9	Cultured fry	1-5	Floating cage (5 x 5 x 5 m)	Formulated powder mixed with fish	8-26

Source: Torishima et al. (1977).

Table 13. Eggs obtained from brood fish of red seabream kept in tanks from April to July 1971-75.

Prefecture	Tank (t)	Water temperature (°C)	Brood fish				Spawn taking		
			Age (years)	Female	Male	Average weight (kg)	Period (days)	No. of eggs laid (10^4)	Eggs/fish (10^4)
Kagoshima	110	--	3	30	30	1.3	>5	4800	160.0
Kumamoto	40	16.4-21.7	4+5	55	45	1.8	54	4800	87.3
Nagasaki	34	--	2	84	82	0.6	72	5040	60.0
	34	16.5-21.7	3	20	20	1.0	56	5603	280.2
	34	16.5-22.2	3	31	30	1.0	61	5523	178.2
Oita	27	--	4	3	4	1.7	24	183	61.0
	77	--	4	5	5	1.8	84	529	105.7
	100	14.7-20.4	3	50	50	1.2	68	5120	102.0
	100	14.7-20.4	5+5	28	28	2.4-5	86	3744	134.0
Fukuoka	5	14.4-21.5	5+6	8	12	2.0	61	2431	303.9
	5	14.3-21.8	4-6	8	9	2.0	87	1805	225.6
Yamaguchi	30	14.9-20.0	5+6	30	13	1.8	47	2300	76.7
Hiroshima	75	14.5-21.6	4	3	4	1.1	69	1009	343.0
	48	16.2-21.4	5	3	2	1.8	67	755	251.6
	48	12.3-17.8	5	3	2	1.2	63	669	223.0
	48	--	5	2	3	1.3	39	616	307.8
	48	--	5	2	3	1.4	45	754	377.2
	5	16.5-23.9	6	1	3	2.1	69	970	970.0
SAC	50	11.6-20.5	7-12	71	71	4.0	77	22137	311.8
	50	12.0-20.6	8-13	62	62	4.5	89	29488	475.5
CEC	12.5	ca 19	4	6	4	1.5	65	1691	281.8

Source: Torishima et al. (1977).

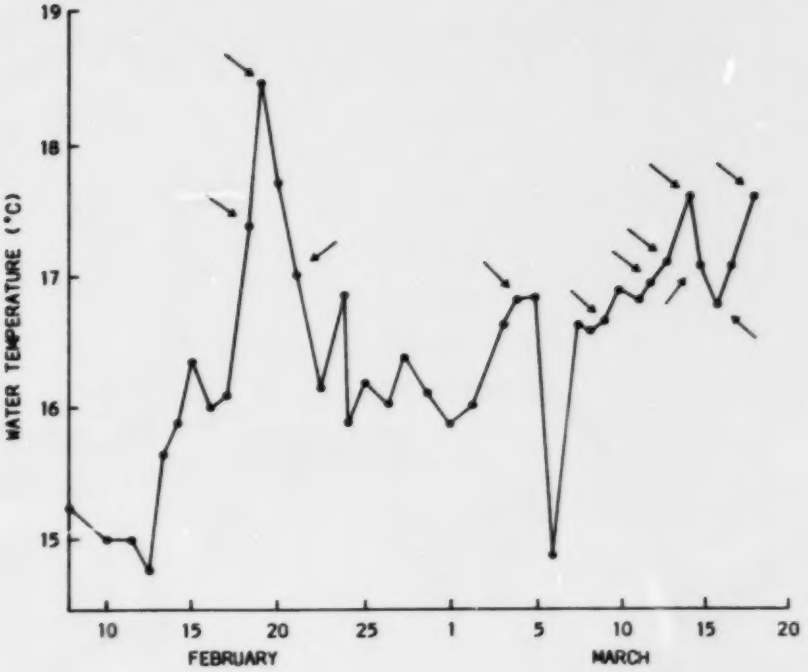

Fig. 11. Results of experiments on the spawning of red seabream kept in tanks and induced by raising the temperature of the tank water by supplying warm water. Arrows show the date and temperature of spawning witnessed. The experiment indicates that spawning takes place naturally in water with a temperature of about 17°C or higher but not below (Hareda 1974 with some modifications).

The red seabream spawn in the tank water without any difficulty provided there is careful management of the tank water. Induced spawning by hormonal injections is not needed for this species.

Hatching

The hatching or incubation tank (0.5-1.0-t capacity) is installed indoors and attached to a compact aeration system. The eggs collected in the spawning tank are first placed in a small pan and cleared of dead eggs and debris. Then, the eggs are placed in a hatching tank. The tank water is kept stagnant but aeration is maintained rather vigorously. One example of an incubation tank is illustrated in Fig. 4c.

At 18°C the eggs hatch about 50 hours after fertilization. The hatchlings float on the surface of the water and 2-3 hours after hatching they start moving vertically. Horizontal movement is

achieved 24 hours later. After a 2-day period the hatchlings become sensitive to foreign substances in the water and 3 days after the yolk is absorbed they start feeding on small live food such as rotifer and artemia. Within 4-5 days after hatching an active search for live food starts accompanied by vertical movement from the surface to the mid-layer. The movement is carried out in schools during the daytime, but toward evening the larvae separate from each other and keep a vertical position with the head down in the mid-layer of the water. When the active feeding behaviour of the larvae is confirmed, they are transferred to the larval rearing tank.

Rearing of Larvae

The larval rearing of the red seabream is usually done in two phases: primary and secondary. The primary phase is conducted in concrete tanks in which the larvae grow from 8-20 mm long. The food supply at this stage consists mostly of live food. The larvae are then transferred to floating net cages or to larger concrete tanks where they grow to a length of about 50 mm. Non-live food comprises the bulk of the food supply at this point (Fig. 12).

Facilities: Concrete Tanks and Floating Net Cages

The concrete tanks used for the primary-phase rearing differ in shape (circular, square, quadrangular) and size (20-200 t), but all of them have a declined bottom to ensure that the water moves smoothly (Table 14). Depending on the structure of the tank a fish-collection area and roofing may or may not be included in the facilities. Two examples of concrete rearing tanks are shown in Figs. 5 and 6. Because the red seabream larvae are fed with live food, facilities for live food mass production along with larval rearing tanks (see Table 6) are usually constructed. (See also Fig. 2 for combined construction of the tanks at Nagasaki Station.)

Larval rearing in the secondary phase is usually done in net cages floating in the water near the shore. The dimensions of these net cages and the size of the net mesh are adjusted according to the size of larval fish reared: 10-20 mm, 2 x 2 x 1.5 m, and 2.2 m; 20-25 mm, 4 x 4 x 3 m, and 3.1 mm; 35-30 mm, 35-30 m, and 4.2 mm; 30-40 mm, 30-40 m, and 5.5 mm; and 40 mm, 40 m, and 7.1 mm for fish size, size of net, and mesh size of net, respectively.

The management of water in larval rearing tanks includes: change of water, addition of chlorella, aeration, lighting, temperature of the tank water, pH value, and chlorine and other chemical components. The brief notes that follow on each of these are based on the results of experiments and experiences at different fisheries stations. It must be noted that these are by no means standardized technology.

- Change of water -- The tank water is kept stagnant for 6-10 days from the start of the larval rearing process. Then, the water is replaced by new water, the amount of which is gradually increased, but on the average the tank water is changed two times over a 24-hour period. The water that is added is either fresh or filtered seawater.

- Addition of chlorella -- The adding of chlorella to the tank water has two objectives -- to clean the water and to feed the rotifer. Chlorella is added for 6-10 days while the tank water

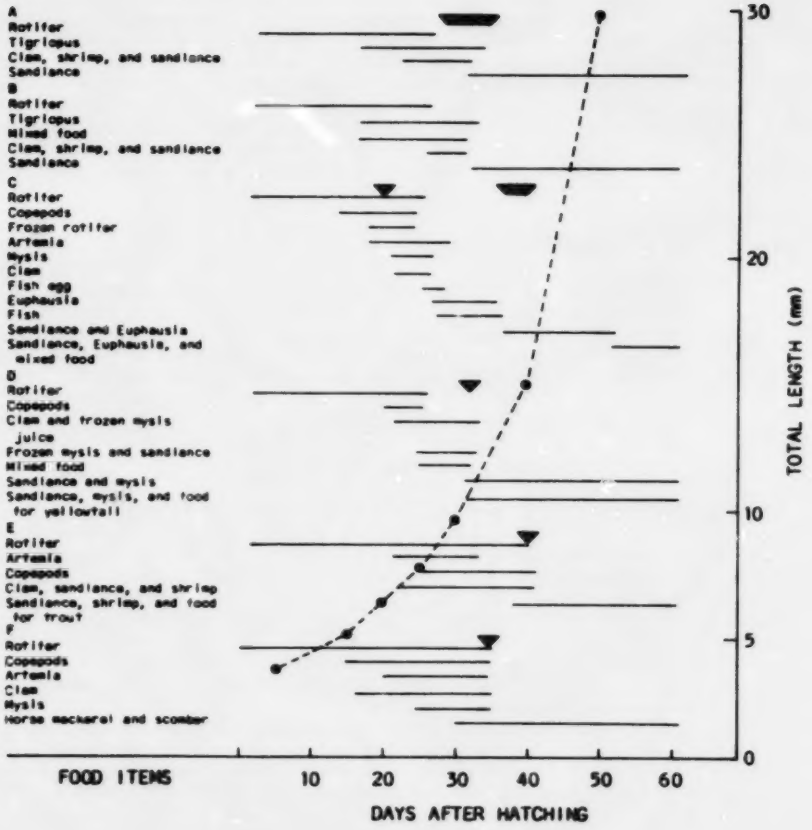

Fig. 12. Food given to the red seabream larvae in the primary and secondary phases of rearing in captivity showing the duration of the feeding for each food item and the routine feeding procedures adopted at the six prefecture fisheries experiment stations (A-F). Triangles indicate the approximate date for changing from the primary to the secondary phase at each station and the dotted line depicts a general growth curve during the rearing: A and B = Nagasaki Prefecture, C = Kumamoto, D = Hiroshima, E = Kagoshima, and F = Taiyo Fishing Co. (Hirata et al. 1977a for feeding procedures and Fujita 1975 for growth rate).

is kept stagnant. The concentration of chlorella is calculated to reach 50 x 10^4/mL of water.

- Aeration -- For tanks with a 40-100-t capacity aeration is usually provided by 10-15 tubes ending in an air stone or one tube for each 3 m^2 of the tank bottom area.

Table 14. Characteristics of tanks used for the rearing (primary phase) of red seabream larvae installed at the five prefecture fisheries experiment stations and the five prefecture fish culture centres. Tanks are either rectangular or circular.

Station and centre	Size of tank (m)	Characteristics of tanks					Size of fish moved to secondary phase (mm)
		Depth of water (m)	Capacity of water (t)	Bottom inclination	Presence of fish-collection area	Roofing	
Nagasaki Station	Dia. 8.0 x 2.1	2.0	100	1/150	None	None	10-20
Kumamoto Station	10.0 x 5.0 x 2.3	2.0	100	1/30-70	Present	Present	8-10
Kagoshima Center	7.5 x 4.0 x 2.0	1.8	54	1/150	None	Present	15-22
Miyazaki Station	6.0 x 3.5 x 1.2	1.0	21	1/120	None	Present	7-10
	Dia. 5.0 x 1.7	1.5	29	--	None	None	7-10
Oita Station	10.0 x 4.0 x 1.2	0.9	36	1/50	Present	Present	12
Hiroshima Station	8.4 x 3.6 x 1.1	0.9	27	1/20	Two present	Present	11-15
Yamaguchi Center	10.0 x 4.0 x 1.5	1.2	48	1/20	None	Present	9-12
	10.0 x 5.0 x 2.0	1.9	95	--	None	Present	9-12
Tottori Center	10.0 x 10.0 x 2.0	1.9	190	1/200	Present	None	10
Ishikawa Center	7.0 x 5.0 x 1.5	1.2	42	1/100	Present	Present	12-13
Niigata Center	Dia. 8.0 x 1.0	0.8	40	1/50	None	None	--

Source: Hirata et al. (1977a).

- Lighting -- Sunlight over the tank water is kept at 20-30 klx by adjusting dark curtains set on the roof.

- Temperature of the tank water -- The temperature of the tank water usually reads 14°C at the beginning and 23°C at the end of the larval rearing process. The lowest temperature is kept at 16°C to ensure the proper growth of the larvae.

- pH value -- The pH value of the water usually ranges from 7.6-8.6 with lower readings in the evening than in the daytime. A reading of more than 8.6 arising from an excess of oxygen derived from chlorella and diatom is avoided.

- Chlorine and other chemical components -- The concentration of dissolved oxygen, NO_2-N, NH_4-N, in the water is affected by a number of factors such as the tank capacity, population density of the larvae, lighting, food supplied, deposited debris, etc. Past experiences have shown optimum readings to be as follows: chlorine 17-18 o/oo, dissolved oxygen 4.00/L, and NO_2-N below 0.5 ppm. The concentration of NH_4-N is kept at the lowest level by cleaning out debris deposited at the bottom of the tank.

Feeding

When yolk absorption is completed (3-5 days after hatching) the larvae that have grown to 3.1-3.2 mm start feeding. Their jaws and digestive system have developed and their vents have opened.

Although the schedule of feeding shown in Fig. 12 differs in some details from one fisheries station to the other, the order of feeding in general remains the same throughout the different stations, i.e., rotifer and copepods supplied in the primary-phase rearing and prepared foods, i.e., formulated and minced food, in the latter portion of the primary phase as well as in the secondary-phase rearing. It should be noted that the change of food items from one to another is always done so that there is an overlap of 2-3 days, i.e., during these days both new and old food items are given simultaneously.

With regard to the feeding of larvae with live food, three points should be noted:

- In the tank water supplied with a substantial amount of rotifer and tigriopus, the larvae that have grown to a length of up to 6 mm feed mainly on rotifer. Once they reach a length of 7 mm, they feed on both rotifer and tigriopus. Larvae that have grown to 10 mm prey more on tigriopus than on rotifer.

- The size of rotifer eaten by the larvae corresponds to the mouth size of the larval fish (Fig. 13). The rotifer eaten by larvae that are smaller than 4 mm measure 200 μm. Those that are 5 mm long prey on 500 μm rotifer. The larvae that are 8 mm in length prey on 900 μm rotifer while 11 mm ones feed on 1200 μm rotifer. It is also apparent that tigriopus are eaten more by the larvae that are 10 mm or longer, as has been noted above.

- In the early days of red seabream larvae rearing (before mid-1954) oyster larvae were used as one of the live food supplied in the initial stages of rearing. However, repeated

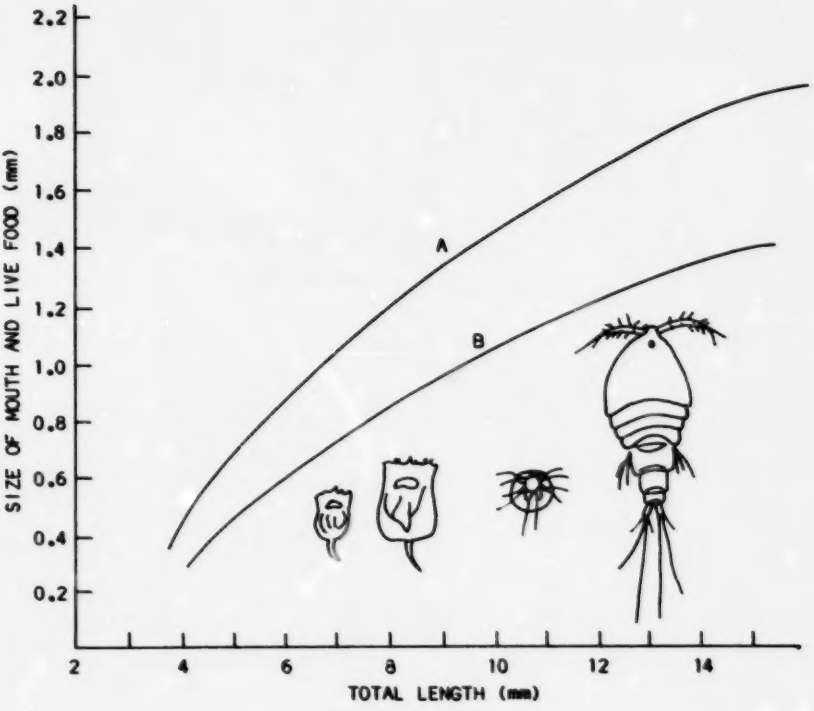

Fig. 13. The increase in mouth size and the size of live food compared with the growth in total length of red seabream larvae. Curve A shows the mouth size (2 x upper jaw length) and curve B the length measurement of the same jaw. Live food, depicted according to mouth size, from left to right, young and adult of rotifer and the two stages of Cladoceran Tigriopus (Yamada et al. 1977 with some modifications).

experiments showed that the food value of the oyster larvae is nearly the same as that of the rotifer's (Fig. 14). Also, compared to the rotifer, the growing of oyster larvae requires more space, labour, and techniques. As a result, oyster larvae are no longer used as live food for the red seabream larvae. Today, red seabream larvae are fed rotifer, tigriopus, and formulated and minced foods.

The amount of rotifer consumed by the red seabream larvae has been studied from various angles including stomach content analyses. It has been noted that at a given time the amount of rotifer eaten by larvae to the point of satiation is equal to 7-10% of the weight of the larvae. It has also been noted that about 50% of the larvae take rotifer to satiation.

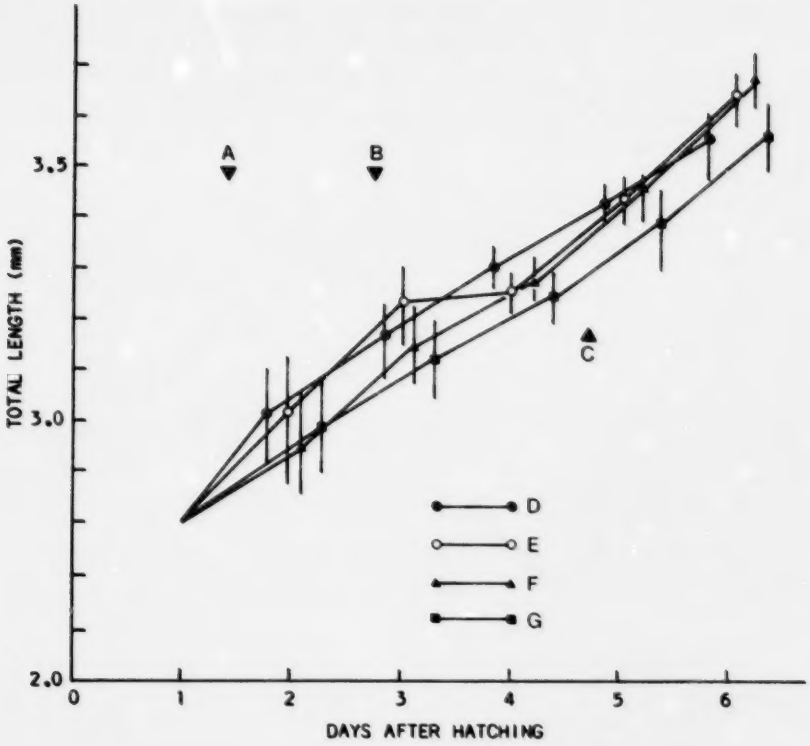

Fig. 14. Results of experimental rearing in terms of the growth in length of red seabream after hatching and feeding with oyster larvae, rotifer, and a combination of the two in water with or without chlorella: A = time of the first supply of food, B = time of the first feeding with larvae, C = time of supply of rotifer to each group, D = feeding with oyster larvae, E = feeding with rotifer, F = feeding with a combination of oyster larvae and rotifer, G = feeding with oyster larvae. In D, E, and F chlorella was added but not in G (Fushimi 1975).

The amount of rotifer consumed per day measured in a 24-hour period (Table 15) varies by the size of the larvae with the amount consumed increasing along with the growth of the larvae. Table 15 also shows that the larvae daily consume rotifer amounting to 40-70% of their body weight. The total amount of rotifer needed to grow 5 million larvae to a length of 10 mm in 20-25 days has been estimated to be 70 million pieces.

The amount of tigriopus taken to satiation by 6-8-mm larvae is equal to 11-14% of the larvae's weight. This value is slightly larger than the corresponding figure for the rotifer (7-10%). The amount of tigriopus consumed per day is calculated to be equal to 47-62% of the

Table 15. Daily rotifer consumption of red seabream larvae traced in the 11 experiments conducted in 30-L containers each, and checked initially every 4 days. Known amounts of rotifer supplied to each container each time and its decrease (or consumption) were checked every 1-2 hours for 24 hours. The daily consumption of rotifer in number, weight, and weight percentage in the table indicates average values of total larvae.

Days after hatching	No. of larvae	Larvae total length (mm)	Average body weight (mg)	Section	Rotifer				Lighting and water temperature (°C)
					Density (no./mL)	Daily no.	Consumption weight (mg)	Weight of larvae (%)	
7	2000	3.92 ± 0.34	0.32	A	12-16	60	0.18	56	Sunlight, 18.7-25.8
				B	6-11	70	0.21	66	
				C	3-5	60	0.18	56	
11	1500	5.09 ± 0.26	1.00	A	7-14	140	0.42	42	Sunlight, 16.8-22.3
				B	4-10	120	0.36	36	
				C	2-5	140	0.42	42	
15	1500	6.68 ± 0.78	3.17	A	6-19	720	2.16	68	Sunlight, 21.3-23.0
				B	1-8	470	1.41	44	
				C	4-17	740	2.22	70	Lighting at night
23	1000	10.05 ± 1.23	13.7	A	2-13	1280	5.46	40	Sunlight, 22.2-23.5
				B	3-14	2520	7.56	55	Lighting at night

Source: Hirata et al. (1977a) with modifications.

larvae's weight. This value approximates the corresponding figure for the rotifer. To grow 1 million larvae to a length of 12 mm within 5 days, the total amount of animalcules to be supplied is estimated to be 1800 million. In actual practice, however, only 33% of this estimated amount (or 600 million) is sufficient because other food organisms are always simultaneously supplied (see Fig. 12).

Feeding with formulated and minced food starts toward the latter portion of the primary-phase rearing as these kinds of food serve as supplements to live food. So far, the precise amount of prepared food required has not been determined, nor has detailed information on satiation, time of digestion, etc. been recorded. In practice, however, prepared food, which is equal to about 15% of the larvae's weight, is supplied five to six times a day for 20-30 mm larvae and three times a day for 50-mm ones.

The larvae transferred to net cages in the secondary-phase rearing are fed minced and formulated food. The amount supplied is adjusted by observing the activity of the larvae. It should be recalled that the larvae in net cages feed on planktonic organisms that enter the cage from the sea.

Growth

The growth of larvae reared in tanks or net cages is affected by many factors (see Tables 16 and 17), however, the growth rate increases rapidly after 30-40 days of rearing. This increase in rate corresponds to the start of the supply of prepared food (Fig. 12). The growth of the larvae by size may be summarized as follows: in the primary-phase rearing they grow to a length of 8-20 mm and in the secondary-phase rearing (in net cages) they can reach 50 mm.

The larvae that are 4-5 mm long move horizontally in the water. They show a tendency to gather toward the brighter zones in the daytime but disperse in the water at night. Usually, the larger individuals stay at the bottom, whereas the smaller ones stay on the surface of the water. Those that are 8-10 mm long show a stronger tendency to gathering than the smaller ones. The larvae that are longer than 10 mm show even more intense gathering or schooling behaviour. In the morning and at twilight they swim on the surface of the water. In the daytime they gather at the bottom of the water or hide under foreign substances. At night they tend to stay closer to the walls of the tank.

Production

Tables 16 and 17 present data from a number of experiments conducted at different fisheries stations on both primary- and secondary-phase rearing. The data include tank sizes, stocking rates, growth rates, and survival rates. From this information the stocking rate shows a positive relation to the survival rate. The data also indicate that the size of the tank and the final production are negatively related.

Diseases and Malformation

Compared to the other fish reared in the country the diseases and malformation or deformation of the red seabream's body structure have been investigated more intensively.

Table 16. Stocking and survival rates of red seabream larvae in the primary-phase rearing period. Data obtained in 1976 from five prefecture fisheries experiment stations.

Prefecture	Size (t) and no. of tanks used	Initial stocking: Total no. of larvae (10^4)	Initial stocking: Rate/t of water (10^3)	Initial stocking: Duration of rearing (days)	End of rearing: No. of larvae (10^4)	End of rearing: Rate/t of water (10^3)	End of rearing: Length of fish (mm)	End of rearing: Survival rate (%)
Yamaguchi	50 x 6	900	30	40	360	12	10.3	40.0
Nagasaki	100 x 3	510	17	26-35	170	5.6	10-17	33.0
Kumamoto	100 x 1	320	32	23-25	192	19	8.5	60.0
Kagoshima	60 x 4	414	10-20	42	28.9	0.9-1.2	15-22.4	6.9
Hiroshima	25 x 6	175	10-15	31-34	23.9	10.5-13.7	10.5-13.7	13.6

Source: Hirata et al. (1977a).

Table 17. Stocking and survival rates and productivity of red seabream larvae reared in tanks (primary phase I) and net cages (secondary phase II). Results obtained from the prefecture fisheries experiment stations (Nagasaki, Hiroshima, and Kumamoto) and the Japan Sea-Farming Association (JASFA) in 1973 and 1974.

Station	Tank capacity (t)	Stocking rate/t (10^4)	Size of larvae attained (mm)	Survival rate (%)		Production/t (10^4)
				Range	Average	
Nagasaki (I)	7-28	1.4-3.9	8.5-12.7	9.3-62.5	19.3	0.15-1.4
	30	1.5-7.5	7.3-11.4	0.8-7.5	5.1	0.024-0.43
Hiroshima (I)	0.5	3.7-9.7	10.0-12.0	25-50	41.0	2.0-5.7
	7-10	0.9-2.1	11.8-23.6	9.3-31.7	15.0	0.09-0.38
Hiroshima (I-II)	50	1.0-1.5	26.8-23.1	2.3-2.9	2.56	0.028-0.034
Kumamoto (I)	0.5	2.4-18.6	7.5-8.6	11.0-68.5	28.8	1.14-4.4
JASFA (I)	50	0.32-0.47	6.9-7.7	13.4-20.7	17.4	0.041-0.096
	200	0.23-0.55	7.9-8.2	12.2-20.8	15.2	0.44-0.08
	25	1.0-1.5	6.8-9.4	1.2-16.7	3.3	0.02-0.06
	150	0.4-0.57	6.8-9.2	4.8-29.6	14.1	0.02-0.13
Nagasaki (II)	5.5 (2 x 2 x 2 m)	0.18-1.74	21.0-43.0	16.0-43.0	33.0	0.13-0.55
Hiroshima (II)	22.5 (3 x 3 x 3 m)	0.024-0.057	--	13.2-78.1	62.1	0.01-0.044

Source: Fujita (1975) with modifications.

Diseases

The diseases caused by bacteria include two types: the swelling of the abdomen and the inflammation of the snout resulting in either a whitish or reddish colour. Both of these diseases are attributed to Vibrio. Abdominal swelling is usually observed among larvae that are smaller than 10 mm. Its infection is believed to come from the yeast-bred rotifer. On the other hand, the snout inflammation disease is frequently observed among larvae that are longer than 10 mm and that are mostly reared in net cages. Its infection is believed to come from external wounds caused by handling.

Other diseases caused by nonbacterial agents have also been observed. One of these is the whitened muscle disease caused by Haloaria. This disease is found more on larvae that are longer than 10 mm and that are reared in net cages. However, the frequency of this disease is much less than those caused by Vibrio. A similar disease, the white-spot disease, caused by a ciliate (Ichthyophthirius), is sometimes observed among larvae reared in net cages. There are also several types of gas-bubble diseases observed among larvae reared in both tanks and cages.

Malformation

There are at least 10 types of body structure deformations among larvae reared in both tanks and cages. Among these the three most common are, in the order of their frequency of occurrence, vertebral bending, centrum fusion, and constriction of the back. The other types of deformation include the shortened or curved opercular bones, pronounced snout, pughead, and poor development of dentary and fin rays or spines (Table 18). It should be noted that the occurrence of these other types of abnormalities today is almost negligible because of recent improvements in feeding procedures.

- Vertebral bending -- The V-shaped bending of the vertebral column is caused by the malformation of the centrum into an unguiate shape with the base longer than the top. This malformation is found most frequently on the 10th and 11th vertebrae located in the abdominal portion but not on those in the caudal portion. This abnormality is also observed more frequently among larvae that are 20-100 mm long. Furthermore, it has been found that vertebral bending is always accompanied by a closed air bladder, another abnormality found among larvae of the same size.

- Centrum fusion -- This malformation is diagnosed externally by a deeper depth of the body caused by a tight fusion of the two centra. The fusion occurs in two or three places separately on the vertebrae (from the second to the 15th) but rarely behind them. The extent of the body depth corresponds to the frequency of the centrum fusion. This abnormality is frequently observed among larvae that are 20-130 mm long.

- Constriction of the back -- The depression on the dorsal contour along the base of the dorsal fin (D. XI, 10) is a result of the dropping or lowering (from the normal position) of two to three dorsal spines downward to the vertebral column together with their proximal zones between the neural spines. The lowering takes place only on the spines, not on the rays, and the position on the vertebral column is not fixed. This

Table 10. Record of body abnormalities found in red seabream fingerlings reared in captivity. Results given are from the studies conducted by nine prefecture fisheries experiment stations, 1975-76. (See text for the symptoms of abnormalities.)

Prefecture/ year	No. produced	Fingerlings			Occurrence of abnormalities (%)				Examination method
		Date of examination	No. examined	Average length (mm)	Vertebral bending	Constriction on back	Centrum fusion	Others	
Nagasaki									
1975	308600	8 July	269	48.7	24.5	0	7.4	0.4	X-ray
1976	276000	7 July	646	51.5	12.7	0	3.6	0.4	X-ray
Fukuoka									
1975	45000	12 September	50	82.4	0	0	10	0	External examination
Oita									
1975	45000	14 October	7010	148.0	7.9	0.1	0.9	0.1	External examination
1976	107000	4 August	604	65.0	2.3	0	0	1.2	Dissection
1976	107000	16 August	95	79.0	10.5	0	0	3.0	X-ray
Kagoshima									
1975	52000	19 June	78	25-36	0-5.6	0	1.4-6.3	0	X-ray
1976	245000	16 June-12 Aug.	321	28-30	1.9-5.6	0-0.5	1.4-6.3	0-1.8	X-ray
1976	245000	19 June	690	15-22	0-1.5	0	0-0.8	0	X-ray
Kumamoto									
1975	259000	—	ca. 1000	ca. 50	2-2.6	1.0	1-1.8	0	X-ray
1976	425000	—	ca. 1000	ca. 50	0-10	0	0-10	0	X-ray
Hiroshima									
1976	139000	3 August-10 Nov.	418	73-110	0-11	0	0-9.9	0	External examination
Ishikawa									
1975	70000	14 July-11 Aug.	1575	28-38	6.4	0	2.7	1.8	X-ray
1976	520000	28 August	108	45-55	7.4	0	9.3	12.0	X-ray
Kanagawa									
1976	153000	20 August	202	61	43.1	3.5	1.5	9.4	X-ray
Mie									
1975	—	8 September	209	95	3.4	0	1.4	0	External examination
1976	—	4 June-15 July	214	30-55	0-3.2	0	0-7.5	0	X-ray

Source: Arisano et al. (1977).

type of abnormality is also found among larvae that are 20-130 mm long.

Causes of Malformation

Despite the number of studies conducted on malformation, no conclusive evidence regarding its causes is available so far. However, five possible causes are: (a) genetic reasons, of which no conclusive evidence is recognized; (b) external injuries, which most probably result from the handling of the fish; (c) muscular constriction by poisoning, of which no conclusive evidence has been observed; (d) nutritional inadequacy, of which no conclusive evidence is available; and (e) mineral deposition, of which no definite evidence is available. Of these, (b) and (d) are more commonly accepted as the major causes. At present, studies on the causes of malformation are still being conducted at a number of fisheries stations.

Sources: Apostolopulos (1976), Arisono et al. (1977), Fujita (1979), Fukuhara (1970a, b; 1977), Fukusho et al. (1976, 1977), Hirata et al. (1975), Okamoto (1969), Smith and Hateya (1982), Torishima et al. (1977), Yamashita (1963a, b; 1964; 1966; 1967; 1971), and Yano and Ogawa (1981).

Black Seabream (*Acanthopagrus schlegeli*) - Sparidae

The black seabream, called kurodai in Japan, ranges from Hokkaido down along the Japanese islands to Taiwan and from Korea along the Asiatic continent down to the East China Sea. The species usually dwells at the bottom of water that is less than 50 m deep and often enter brackish waters. The kurodai grows to 40 cm long in 6-7 years. It is a popular food fish, although it is not as highly valued as the red seabream. The kurodai is also a popular sport fish.

The species is often cultivated with the grey mullet in brackish-water ponds constructed on the shore or in floating net cages. The scope of its cultivation, however, is not as intensive as that of the red seabream or yellowtail. The fingerlings are obtained either from the sea or by artificial spawn taking and larval rearing. At present, however, the cultivation of the kurodai depends mostly on artificial rearing. The discussion that follows on the larval rearing of the kurodai is divided into two: the collection and rearing of natural larvae and artificial spawn taking. The data are based mainly on the work of Hirano (1967, 1969). According to the Japan Sea-Farming Association, 3,805,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The larvae that are grown to a size of 30 mm or so are used as seedlings for further cultivation in captivity, but they are not restocked to the sea.

Collection and Rearing of Natural Larvae

From May to July the 1-4-cm long larval fish assemble on seaweed beds from which they are collected by a larval net. The collected larvae are then placed in oxygenated containers and transported to the cultivation site where they are stocked into cage nets placed in a

brackish-water pond. The larvae stocked in the cage feed on plankton organisms in the pond water. Minced fish is also supplied as auxiliary food. The fish in the cage grow to 10-14 cm long and weigh 35-50 g by the end of November.

The young fish (2 years old) that are 11 cm or so and weigh 30-50 g are also collected by small set nets placed in the shore water from May to July. The young fish trapped in the set net are moved to a brackish-water pond 1 m deep and are fed dried silkworm pupae, wheat bran, and minced fish. They grow to 180 g in weight by the end of the year at which time they are used as seedlings for further cultivation.

Artificial Spawn Taking

Brood Fish and Spawn Taking

The black seabream spawns from April to mid-June when brood fish are available from the catches of commercial fishing. The males mature when they are 3 years old but the females reach maturation in 4 years or later. (Consequently, in a natural population the females are more plentiful than the males.) Naturally, spawn taking is dependent on adult fish cultivated in ponds. The fish are induced by hormone injections. The adult fish used for spawn taking are kept in tanks supplied with warm water and substantial food.

The large fish (4 years old or more) are taken from the pond from mid-April to the end of May and transferred to a tank that is supplied with running seawater with 15-18‰ salinity. The brood fish are kept in the tank for at least a week or so after which they are given a hormone injection. For the injection, synahorin 40 RU/fish is used. The fish are then returned to the tank. Egg collection and insemination are done 40-50 hours after the injection. Insemination is done through both the "dry" and "wet" methods. Experiences show that insemination should be made within 30 min after the eggs are stripped because the rate of fertilization is lowered if more time elapses.

The hatching of the eggs is conducted in incubation or hatching tanks or in larval rearing tanks. The water in the tank is kept at 14 o/oo or higher in salinity and at around 18°C in temperature. Records show that the eggs placed in water that is 15.5-18.5°C in temperature and 14.3 o/oo in salinity hatch in 65-75 hours after insemination, a hatching rate of 17.8%, whereas the eggs in water that is 18.2-20.5°C in temperature and with 16.7 o/oo salinity hatch in 40-44 hours, after a hatching rate of 72.7%. The hatchlings measure 1.70-2.18 mm long. Within 2-3 days they absorb the yolk, attain the size of 2.2-2.7 mm, and start feeding.

Rearing of Larvae

No specific type of tank is used for the rearing of the black seabream larvae. Usually, they are reared in indoor tanks with a surface water area of 3-10 m^2 and that are provided with a running water system and lighting. The larvae are stocked in the tank at a rate of 9000-10,000 pieces/m^2 of water. The lighting is controlled such that it is 5000-6000 lx 5 days after hatching to stimulate the feeding activity. The tank water is gradually increased from 50-70 cm 14-18 days after hatching. The lighting is also lowered to 1000 lx from 20-40 days after hatching.

Feeding

The feeding of the larvae starts 2-3 days after hatching (see Fig. 16). The first live food given is the trochophore larvae of oysters. These are given once a day at the rate of 10 pieces/L of water for the first 2-4 days. This oyster feeding lasts for about 2 weeks with the amount given increasing gradually to 100 pieces/L of water.

The larvae of balanus are given next. These are fed to the fish beginning 2 weeks after hatching until the 24th day. The balanus larvae are obtained from balanus animals attached to bamboo sticks that are placed in the tank. A year before the larval rearing of the black seabream is undertaken these bamboo sticks are planted on the rocky sea bottom where the balanus animals abound. The balanus larvae in the seawater settle on the surface of the bamboo sticks. The bamboo sticks bearing the balanus animals are then cut to suit the water depth in the tank. The density of the balanus larvae has not been determined, but past experiences have shown that the following method ensures the proper collection of the balanus larvae. One to two pieces of balanus-bearing sticks are placed in each square metre of the tank bottom for 10-20 min. This operation is repeated three to four times a day. The balanus larvae that come out during this limited time are sufficient to feed the larval fish. Care must be made not to keep the sticks in the tank longer than what the method specifies. Otherwise, the balanus could grasp and eat the larval fish.

The third type of live food given to the black seabream larvae is copepods from either sea water or fresh water. These are fed to the larvae once or twice a day for about 2 weeks beginning from the 18th day after hatching. The larvae that have grown to a size of 10 mm or more 35 days after hatching are able to feed on prepared fish and formulated food.

The food described so far are examples of food items generally used for the rearing of black seabream larvae. In recent years, rotifer has also been used.

The larvae that have grown to 30 mm or so in size are further reared in the same tank or moved to another tank as they enter the secondary-phase rearing (Table 19) that lasts for 20 days or so. The larvae in the secondary phase are fed with prepared food such as chopped fish. The amounts given are shown in Table 19. The larval fish that are 10 cm in length and weigh 10 g or so are ready for pond culture.

Growth

The growth of the larvae reared in the primary and secondary phases may be summarized as follows: In the primary phase a 2.5-mm hatchling grows to 30 mm in 1.5 months, and, in the secondary phase, it grows from 30 to 100 mm.

Production

During the primary-phase rearing two critical periods have been observed. The first falls on the 5th to the 7th day and the second occurs 12-15 days after hatching. In the first period, the larvae die due to an insufficient supply of oyster larvae and insufficient

Table 19. Record of rearing black seabream larvae in tanks (10-6 m^2 x 1.5 m) fed with scomber (fresh and frozen). The larvae used were obtained on 25 May by artificial hatching.

			Fish larvae								
Date	Period (days)	Tank no.	Starting no.	Starting total weight (g)	Starting average weight (g)	Final no.	Final total weight (g)	Final average weight (g)	Survival rate (%)	Food given (g)	Food coefficient
15 July -	19	I	1058	424	0.4	1051	1808	1.7	99	6220	4.49
3 August		II	1058	418	0.4	1014	2221	2.2	96	7065	3.91
4 August -	23	II	500	860	1.7	490	2436	5.0	98	6508	4.13
27 August		III	500	1095	2.2	487	2697	5.5	98	6110	3.81
		IV	500	1080	2.2	301	1150	3.8	60	5048	--
28 August -	25	III	100	497	4.97	95	1429	15.0	95	2880	3.09
22 September		IV	100	506	5.06	92	1184	12.9	92	2720	4.00

Source: Hirano (1967) with modifications.

lighting. In the second period, the larvae fail to feed properly on balanus larvae. Solutions to the problems are the adoption of rotifer as a substitute for oyster larvae and balanus larvae and the extension of the lighting supply. No definite survival rates for the black seabream larvae have been recorded.

In the secondary-phase rearing (Fig. 15) hardly any mortality has been observed, thus, survival rates are 92-99%.

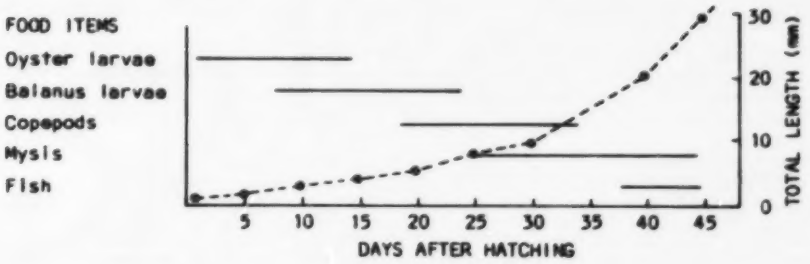

Fig. 15. Food given to black seabream larvae reared in captivity showing the duration of feeding for each food item and approximate growth rates during the rearing period (Hirano 1967 with modifications).

Disease

The gas disease is sometimes observed among black seabream larvae reared in tanks. This disease is caused by an excess of oxygen content in the water, resulting, no doubt, from an overgrowth of phytoplankton or green algae.

Sources: Hirano (1967, 1969), Kasahara and Oshima (1960), and Okauchi et al. (1980).

Striped Knifejaw (*Oplegnathus fasciatus*) - Oplegnathidae

The striped knifejaw, known as Ishidai in Japan, is a coastal fish that ranges from Hokkaido down along the Japanese islands to Taiwan and from southern Korea down along the Asiatic continent to the northern part of the East China Sea. The larval fish tend to follow floating seaweeds. The young (30-40 mm) leave the seaweeds and swim in the mid-layer of water usually forming small schools. Subadult and adult fish measuring 100 mm or more tend to gather in rocky crevasses or underneath large stones. The species grows to 70 cm but those that appear on the market measure only 40-50 cm. The ishidai is a popular food fish especially in southern Japan and fetches a relatively high price in the market.

In the Kyushu region, the cultivation of the striped knifejaw has been as common as the red seabream and yellowtail. The fingerlings are collected together with the young of the yellowtail or trapped in set nets operated for different species of fishes. Because of an insufficient supply of fingerlings from the sea as a result of too

much cultivation, ishidai fingerlings have been imported from Korea or brought over from the northern parts of Japan. Under these circumstances experiments on the production of larval fish in captivity started mainly in the Kyushu region in mid-1970. The general aspects of the larval rearing of the striped knifejaw that follow refer mainly to the work of Fukusho et al. (1978) and Fukusho (1979). According to the Japan Sea-Farming Association, 509,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The fingerlings produced in captivity are used for continuous cultivation mostly in net cages but not for restocking to the sea. The fingerlings, as noted earlier, are collected together with yellowtail larvae but the supply from the sea hardly meets the demand.

Brood Fish and Spawn Taking

Four procedures are followed in the collection of the eggs: stimulation by hormone injection of adult fish caught from the sea, cultivation to adult size of young fish collected from the sea with maturation induced by hormone injection, natural spawning of brood fish in captivity, and natural spawning of brood fish grown in captivity but started from artificially obtained fingerlings. The following accounts are more detailed explanations of the first two procedures listed above.

Brood Fish Caught in the Sea

The mature male and female fish are selected from the catches of set nets operated on a commercial basis. The females are identified by their swollen bellies. The sex of the fish measuring over 35 cm long and weighing over 800 g are distinguished by their coloration, i.e., the females are a dark grey colour with four darker cross bars, whereas the males are a grayish colour without cross bars.

The selected brood fish are transported to the hatchery site and placed in net cages. The inducement for maturation is done with synahorin, the dosage of which is 40 RU/kg of fish weight. The injection is given into the dorsal muscle. The treated fish are then returned to the cage and eggs are collected by stripping 1-3 days after the injection. The dry method is the usual procedure for insemination.

Production of Eggs

The eggs obtained from the brood fish vary in number by the size and nature of the fish, i.e., whether it is natural or reared. The results that follow are of experiments conducted at the Nagasaki Prefecture Fisheries Experiment Station from 1972-73.

- Among 51 females (3.0-3.5 kg in weight) obtained in set net catches, 31 fish spawned by hormone injection. One female discharged 706,000 eggs on the average, but 20.3% of these eggs lost their pelagic nature.

- The spawners (2 kg in weight) that started as natural larvae but were reared in net cages for 4 years discharged 308,000 eggs on the average. Of these 30.7% lost their pelagic nature.

- The 21 females and 15 males that started as artificially produced fingerlings and were cultured in net cages for 2-4 years spawned naturally and produced 1,980,000 eggs on the average. Of these 18.3% lost their pelagic nature.

The eggs produced were placed in an incubation tank where they hatched some 35 hours after insemination. The water temperature was 20-23°C.

Rearing of Larvae

The procedure and scope of larval rearing described next resulted from experiments conducted at the Nagasaki Station. In these experiments, rotifer grown by different media was used as the main live food.

A circular outdoor tank with a capacity of 100 t (diameter = 8 m, total depth = 2.5 m, and water depth = 2 m) was used. Sunlight was controlled by two sheets of dark cloth placed over the tank. The water was aerated with compressed air for 24 hours through 15 air stones.

The rearing period lasted for 40 days, i.e., from 12 June to 30 July. The tank water was moved by adding 20 t of filtered water per day starting from the 2nd day of rearing. The amount of water added was then gradually increased until it reached 500 t/day at the final stage of rearing. In addition, a total of 36 t of chlorella seawater was added from the 1st to the 18th day. During the 40-day rearing period, the temperature of the water was kept at 21-27°C and the pH value at 8.10-8.70.

Feeding

Six kinds of live food and formulated food were used for feeding the larvae. They were supplied in the following order: rotifer fed with chlorella (2 hours); rotifer fed with bakers' yeast (4-20 hours); rotifer fed with special yeast (fat and oil assimilated); copepods (tigriopus cultured and other copepods collected from the sea); formulated food (fish meal 64%, egg yolk 9.2%, yeast 4.6%, minerals 4.0%, vitamins 4.0%, cod liver fat 7.0%, etc.); and fish paste (minced sandlance, euphasia, and clam mixed together).

The order in which each food item was given, the length of time it was given, and the amount of daily feeding are presented in Fig. 16. The rotifer and copepods were put directly into the tank water, the formulated food was spread over the water surface, and the fish paste was spread on the net (30 x 20 cm), which was hung 30 cm below the surface of the water. The total amount of food supplied during the 40-day rearing period amounted to about 26,800 million rotifer, 8.6 kg of copepods, 8.1 kg of formulated food, and 24.5 kg fish paste.

Growth

The hatchlings that were 2.5 mm in length on the average grew into fingerlings that were 24 mm in length during the 40-day rearing period. The growth curve in Fig. 16 is a smooth line and its rapid upward rise occurs after the 30th day when the supply of fish paste was started.

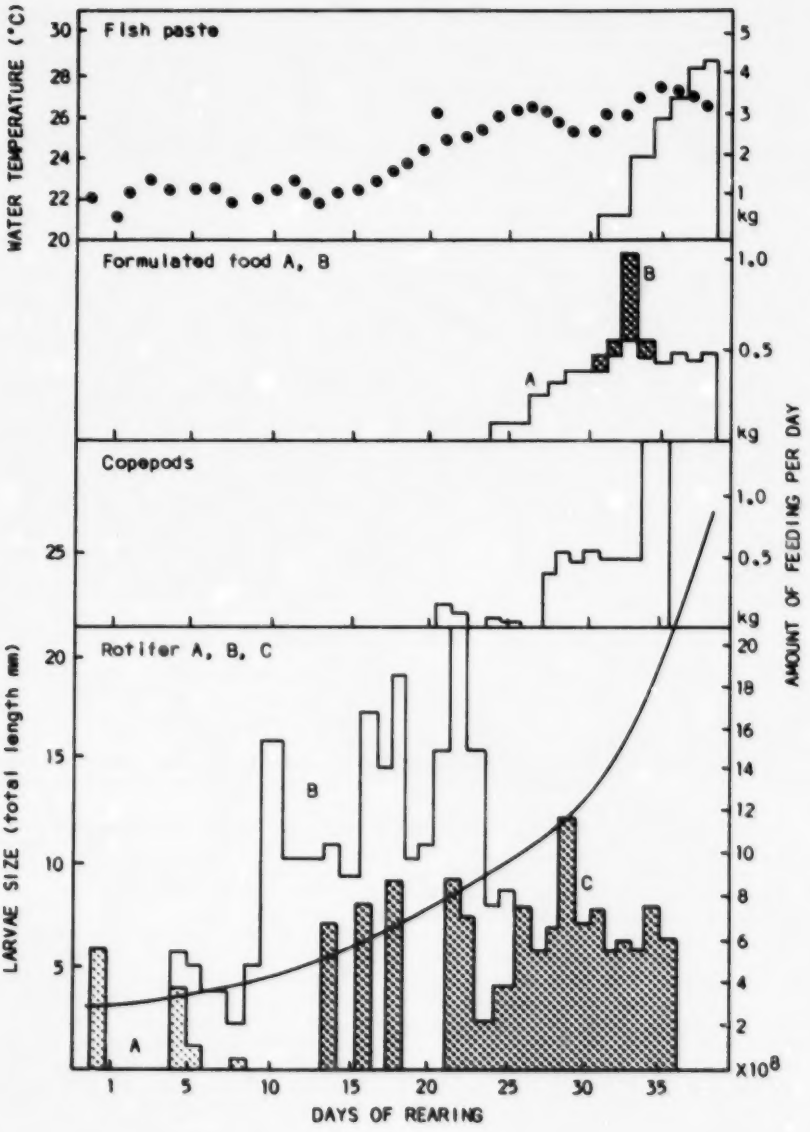

Fig. 16. The 40-day rearing period of the striped knifejaw (12 June - 20 July 1977) conducted in a 100-t outdoor circular tank. In the bottom square, the small dotted bars (A) indicate the rotifer fed with chlorella; the opened bars (B) bakers' yeast; and the large dotted bars (C) special yeast. In the second square, the white bars (A) indicate formulated food and the dotted bars (B) formulated food mixed with fish paste. (Fukusho et al. 1978 with modifications).

Production

In the collection or harvesting of the fingerlings reared in the tank, first, the tank water was reduced to 15 cm deep. The fish in the bottom water were then encircled with a cloth net after which they were scooped up by a dip net. About 60,000 fingerlings were harvested after 40 days of rearing.

Diseases

No symptoms of any particular diseases were observed in the experiments carried out at the numerous fisheries stations. However, some abnormal colour patterns, i.e., cross-bars on the sides of the body were noted. The frequency of these cases were as follows: 23.2% among fingerlings derived from brood fish collected from the sea, 34.5-35.0% among fingerlings derived from brood fish grown from natural larvae, and 47.5-81.3% among fingerlings derived from brood fish grown artificially. Because this pattern was observed in less than 20% of the natural larvae collected from the sea, the frequency of its occurrence positively corresponds to the length of rearing under captivity.

Sources: Fukusho (1973, 1976, 1977, 1979), Fukusho et al. (1975, 1978), Fukusho and Nishinaka (1979), and Ito (1978).

Redeye Mullet (*Liza haematochelia*) - Mugilidae

The redeye mullet, called menada in Japan, ranges from Hokkaido down along the Japanese Islands to the Ryukyu Islands and from Korea down along the Asian continent to the East China Sea. The menada dwells in coastal waters with muddy bottoms and does not migrate. The species shows wide adaptation to temperature, salinity, and turbidity of water. The redeye mullet is an omnivorous feeder and grows to a length of 1 m in the sea. As a food fish it is not as popular as the gray mullet (*Mugil cephalus*).

At present, the gray mullet is commercially cultured in brackish-water ponds. With the exception of some experiments, however, the redeye mullet has not been similarly cultivated. Because the menada shows much potential for cultivation, experiments on the artificial spawn taking of this species were started in early 1970 in the Kyushu region. The accounts given here refer mainly to the experiments conducted in Kyushu in 1970-78. According to the Japan Sea-Farming Association, 20,000 fingerlings were produced in Japan in 1980.

Uses of Fingerlings

The fingerlings obtained artificially are used for cultivation in brackish-water ponds as their restocking to the sea has not yet been considered.

Spawn Taking

In the Kyushu experiments, the eggs were obtained from gravid females that were 340 mm long or longer. These females were selected from catches from the sea. The males that were 270 mm or longer were also taken from the catch. The insemination of eggs was done on board the fishing boat in April. The eggs were then brought back to the

hatchery site and placed in a hatching tank. The eggs hatched 56-61 hours after insemination in water with a temperature of 16-18.9°C. The hatchlings measured 2.2-2.82 mm long.

Rearing of Larvae

The indoor rearing tank had a 12-t capacity. Inlet and outlet canals and two or three air stones were attached to it. The rearing, which began on 16 April, lasted for 70 days. The tank was filled with seawater containing chlorella. For 7 days after the start of the rearing period the tank water was kept stagnant. After that, the water was replaced daily with new filtered seawater amounting to one-third of the tank's capacity. Aeration was maintained throughout the duration of the rearing.

Feeding

The food given and the duration of feeding (after hatching) in the 1971 experiment were: oyster larvae, 5-8 days; rotifer, 6-32 days; artemia nauplii, 12-40 days; copepods, 23-40 days; and minced fish, 35-62 days.

The amount of food supplied was adjusted to the feeding activity of the larvae. For about 1 month after being hatched the larvae moved on the surface and in the mid-layer water seeking live food. After that, they stayed mostly at the bottom feeding on minced fish.

In the 1972 and 1978 experiments, the food given to the larvae was somewhat different from that provided in the experiment noted earlier. But, the amounts of rotifer given in the earlier period of the 1972 and 1978 experiments and the minced fish given toward the end were about the same as that in the 1971 experiment.

Growth

The growth of the larvae in the 15-t tank (water temperature of 19.1-24.6°C) from 16 April to 25 June 1971, was as follows: a 2.3-2.8 mm hatchling (average size of 2.56 mm) grew to 3.5-4.4 mm or an average of 3.83 mm 7-8 days after hatching when the yolk was completely absorbed. About 30 days later, some of the fast-growing fish reached a length of 14-15 mm completing metamorphosis in shape and coloration. The majority of the larvae, however, attained this size between 35 and 40 days after hatching. They then showed sedentary feeding habits on minced fish. The 30 mm size was attained 55-60 days later, and, the largest size, 26-59 mm or an average of 46.8 mm, was reached at the end of the rearing period or 70 days after hatching.

Production

In the 1971 experiment, the hatchlings numbered 250,000 and the harvested fish totaled 100,000 indicating a survival rate of 40%. In the 1972 and 1978 experiments, the survival rates were calculated to be 48% and 30%, respectively. These figures are rather high compared to the survival rates of other species. This high survival rate is believed to have been partly a result of the lack of cannibalism among this species.

Disease and Malformation

No symptoms of diseases nor abnormal body structure were noted in the experiments described here.

Sources: Fujita (1979) and Fukusho (1972).

Yellowfin Tuna (Thunnus albacares) - Scombridae

The yellowfin tuna, known as kihada-maguro in Japan, is found in the tropical and subtropical seas of the world with the exception of the Mediterranean Sea. Along the western Pacific shoreline the species ranges from Hokkaido to the southern Japanese islands and further on to the Indonesian archipelago, to Cape Howe in Australia, and, finally, to New Zealand. Like the blackfin tuna, the yellowfin tuna grows to a size of 2 m. It is also a popular food fish in Japan.

The cultivation of the kihada-maguro in captivity has been attempted by a number of fisheries agencies, but the scope of its cultivation has not yet reached the level of commercial operation. Thus, no statistical figures exist at present. However, egg collection from natural brood fish and the rearing of hatchlings to larvae that are 8.5 mm long have been undertaken. The accounts that follow are limited to spawn taking on board fishing boats and the rearing of larvae in tanks. These accounts refer mainly to the work of Mori et al. (1973) and Harada (1971).

Uses of Fingerlings

As already mentioned, the work done on the kihada-maguro is still at the experimental stage; thus, the uses of fingerlings have not yet been definitely determined.

Brood Fish and Spawn Taking

These procedures were carried out on a purse-seine boat that was operating at sea some 15 km off the Mie Prefecture coast. From among a total of 26 fish that were caught using the boat, two mature female fish were used as brood fish (26 July 1972). Stripping from one of the female fish (150 cm long and 60 kg in weight) produced 42,000 eggs. The other female fish (same size and weight) produced 855,000 eggs. Egg stripping and insemination (dry method) were carried out on board. The collected eggs were placed in an oxygenated polyethylene bag and brought to the Prefecture Fisheries Station, a 5-hour trip. The two lots of eggs were placed in separate hatching tanks. The eggs that developed to the morula stage in the tank water amounted to 340,000 and 570 million, respectively. The hatching rate was, therefore, 81% and 67%.

Ten thousand eggs were scooped out from the stock in the hatching tank and transferred to a 1-t-tank filled with green seawater. The eggs in the tank hatched 24-38 hours after insemination. The tank water temperature was about 26.1°C. The total number of hatchlings amounted to 3500 pieces showing a hatching rate of 35%. The hatchlings measured 2.7 mm on the average, were reared in the same 1-t tank, and fed with oyster larvae and rotifer. Some of them grew to 5 mm long but all of them died after 8-9 days of rearing.

Rearing of Larvae

A portion of the eggs collected on board the purse-seine boat (26 July 1972) was brought to the Kinki University Laboratory in Wakayama Prefecture where egg hatching and larvae rearing were conducted. The eggs were placed in containers of different sizes for hatching. The rate of hatching ranged from 0.35-8.1%. The hatchlings were also reared in tanks of different sizes.

The larval rearing was conducted in a 15-t tank for a period of 20 days. The tank was filled with filtered seawater containing chlamydomonas. The water was kept stagnant for the first 15 days of the rearing period. After that, the water was constantly replaced and, therefore, kept moving. The temperature of the water during the 20-day period was recorded at 25.6°C. On 27 July, about 100,000 eggs were placed in the tank. The following day they hatched into 350 hatchlings, a rate of only 0.35%.

Feeding

The food supply consisted of cultured rotifer and copepods collected from the sea. Rotifer was given on the 2nd to the 10th day and the copepods from the 8th day to the end of the rearing period.

Growth

The measurements made on sampled specimens showed the following growth rates for 2.3-mm hatchlings: 2nd day, 3.6 mm; 7th day, 5.0 mm; 10th day, 6.3 mm; and 18th day, 8.5 mm.

The hatchlings were observed floating on the surface of the water. They kept their bodies in a lateral position with their yolks on their backs. As the days passed they began moving vertically. On the 2nd day after hatching lateral movement was added to the vertical movement. Feeding started from the 3rd day when the absorption of the yolk was completed.

Production

The 350 hatchlings decreased to 150 within 6 days after hatching and to 120 on the 11th day. By the 18th day after hatching all the larvae were found dead. The mortality rate was inversely correlated with the growth rate.

Disease and Malformation

Within the limited duration of rearing (9-18 days) no symptoms of disease nor abnormality of body structure were observed.

Sources: Bayliff (1980), Harada et al. (1971), Mori et al. (1971), and Ueyanagi et al. (1973).

Japanese Flounder (*Paralichthys olivaceus*) - Bothidae

The Japanese flounder, a left-sided flatfish known as hirame, ranges from the Sakhalin and Kurile Islands down along the Japanese island, to Kyushu, and along the Asian continent down to the northern part of the East China Sea. The usual habitats of the hirame are

sandy bottoms 100-200 m deep but they move to shallow waters (20-40 m) for spawning. The species grow to a length of 80 cm and weigh about 5 kg in 7-8 years.

Among the heterosomate fishes in the country, the hirame has been regarded as the most delicious; thus, it fetches the highest price on the market. The practice of keeping adult fish in captivity after they are caught in the sea has a long history, but artificial spawn taking and the rearing of larvae began only around the mid-1960s. Accordingly, the technology on these subjects has not yet been developed to the level of standardization. The accounts presented here refer mainly to the experiments conducted in 1978-79 at the Tottori Prefecture Fisheries Experiment Station, which faces the Sea of Japan. According to the Japan Sea-Farming Association, 4,816,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The larval fish reared to fingerlings that are about 14 mm in size and have settled at the bottom of the tank (primary phase) are further reared in net cages to reach a length of 30 mm (secondary phase). The young fish of this size are used as seedlings for further cultivation in captivity to marketable size or used as material for restocking to the sea.

Brood Fish and Spawn Taking

The larval fish are obtained through artificial procedures, i.e., not from the sea. The fish derived from artificial hatching procedures and grown to adult size in captivity have not yet reached maturation.

Brood Fish

Brood fish measuring 25 cm or more were selected from the catches of fishing operations from March to May. They were brought to the station and placed in an indoor circular tank where they were kept for about a year.

This indoor tank had a 10-t capacity (3.7 m in diameter and 1 m in depth). It was filled with 8 t of raw seawater and equipped with a water supply and drainage system as well as aeration and egg-collecting apparatus. Three-fourths of the tank area was covered by a sheet of dark canvas.

The fish placed in the tank were fed mackerel, sardine, seabass, etc. The feeding lasted throughout the spawning period that started on 16 March (water temperature at 14.5°C) and ended on 29 June (106 days). There was a total of four females (17.5-60.5 cm) and eight males (50.0-72.5 cm) engaged in spawning. No hormone injections were needed.

The pelagic eggs that floated into the egg-collection device were collected throughout the 106 days. The eggs were counted using the weight method. (There were 1800 eggs/g.) The total number of eggs deposited by the four female fish amounted to 16,171,700 pieces or 4,042,925 per fish. It was observed that the peak of the egg-laying activity occurred for about 10 days in early April when 82% of the total number of eggs were laid. The actual egg-laying process lasted for 78 of the 106 days.

Hatching

The eggs collected in the spawning tank were stocked into an indoor hatching tank (1 x 1.6 x 0.6 m). The tank water was aerated and kept in motion (10-20 L/min), and the tank interior was dimmed by setting a dark board on top of it. The eggs were placed in a net cloth (35-90 cm in diameter and 40 cm deep), which hung inside the tank, and hatched 49 hours after insemination. The temperature of the tank water was 16-20°C. The hatchlings measured 2.4-2.6 mm.

The dead eggs that sank to the bottom of the net were picked up by a siphon several times a day; thus, the number of the eggs that hatched were accurately counted. The rate of hatching was also estimated accurately. The total hatching rate during the entire 100-day period was 75.9%. A higher rate (79%) was noted in the first 40 days. Later, the rate decreased to 35%. The largest daily count, 678,000, was recorded on 7 April. These figures indicate that the number of eggs laid corresponds to the rate of hatching, which suggests that the best period for spawn taking of the hirame falls in April.

Rearing of Larvae

The information on larval rearing was also derived from the experiments conducted at the Tottori Station. These data are believed to be more substantial compared to other available published accounts.

Primary Phase

A total of five outdoor tanks was used. Each tank measured 2 x 4.9 x 1.3 m and had a 10-kL capacity. The tanks were filled with filtered seawater that was aerated by six air stones in each tank. The temperature of the water was kept at 17-20°C with the aid of heaters. The tanks were placed under a blackboard to control the intensity of the sunlight.

During the 33-35 days of larval rearing, the water in each tank was replaced by new water (2.5 kL) every 2 days until the 10th day, after which the amount of new water increased gradually until the end of the rearing period. In the second half of the rearing period the amount of new water reached 5 kL/day. The salinity of the water ranged from 1.02554-1.02681. The rearing period lasted from 33-35 days during the months of April-June (Table 20).

Secondary Phase

Three net cages, each measuring 1.0 x 1.5 x 0.5 m, placed in each of the two tanks were used for rearing. The net itself had a mesh size of 3.1 mm. Each tank measured 4.9 x 2 x 3.1 m, and both were placed under a roofing. The supply of filtered seawater was provided through two channels, one for each of the cages and another for the tank as a whole. A tube with openings underneath was placed over the tank. The openings were located above each cage. The water supply canal for the tank opened on the tank wall close to the bottom and an overflow tube was placed on the opposite side of the canal. The water supplied by the tube over the tank flowed inside the cages and was mixed with the supplied feeds. The water supplied through the canal on the tank wall flowed on the tank bottom, thus effecting the decomposition of debris deposited there. Eventually, the debris floated up to the opening of the overflow tube. The water was aerated by two air stones in each cage.

Table 20. Rearing of the Japanese flounder larvae in the five tanks (each 10 kL in capacity) for 33-35 days. The hatchlings (2.4-2.6 mm) that were stocked attained an average size of 13.92 mm at the end of the rearing period. Rotifer was given from the day of larvae stocking to the end and artemia naupili from the 10th day to the end.

Tank no.	No. of larvae stocked ('000)	Dates of rearing (day/month)	Fingerlings harvested			Food supplied	
			No.	Production (per kL)	Survival rate (%)	Rotifer (10^7)	Artemia (10^6)
1	130	24/04-29/05	65744	6575	50.57	211.1	511.5
2	120	25/04-30/05	29176	2916	24.30	158.0	296.5
3	120	11/04-23/05	28441	3844	32.03	193.5	191.5
4	120	20/04-27/05	45516	4552	37.93	189.36	218.4
5	170	03/05-06/06	60813	6081	35.77	279.5	121.5
Average	132	34.5 days	47934	4793	36.31	206.0	267.4

Source: Hiramoto et al. (1980) with modifications.

Table 21. Data from rearing of Japanese flounder juveniles in six net cages placed in two tanks showing the stocking, management, and harvesting. (For facilities, management, and feeding, see text.)[a]

Tank and cage no.	Stocking of larvae			Harvest of fingerlings			
	Date	No.	Average size (mm)	No.	Range of size (mm)	Average size (mm)	Survival rate (%)
Tank I							
1	20 May	10000	15.2	7451	18.0-45.0	30.9	74.5
2	20 May	20000	15.2	13886	--	--	69.4
3	20 May	30000	15.2	22170	--	--	73.9
Tank II							
1	2 June	10000	15.9	5631	28.4-90.0	39.8	56.3
2	2 June	20000	15.9	10000	--	--	50.0
3	2 June	30000	15.9	17342	--	--	59.5
Total or average		120000	15.5	33479	18.0-90.0	34.7	63.9

[a] For tank no. I the duration of rearing was 24 days at a water temperature of 17.5-21.1°C and the total weight of food supplied per tank was 47,052 g. For tank no. II the duration of rearing was 28 days at a water temperature of 18.8-23.5°C and the total weight of food supplied per tank was 73,421 g.

Source: Hiramoto et al. (1981) with modifications.

The tank water was replaced by new water at 35-95 L/day throughout the rearing period (24 days for tank no. 1 and 28 days for tank no. 2). The dead fish were picked up by a siphon and counted every day, and the net cages and the tank were cleaned several times during the rearing period.

The temperature of the water was recorded at 17.5-23.5°C and the salinity at 1.0240-1 - 1.0265. The light intensity on the surface of the water measured 5000-10,000 lx even on bright days, therefore, no growth of phytoplankton was observed.

Feeding

The feeding in the primary and secondary phases differed in terms of the food given and the duration of feeding. During the primary phase (35 days) the rearing started with the stocking of hatchlings 1.6-2.4 mm long. These hatchlings were produced artificially. Three kinds of rotifer and artemia nauplii were given once a day in the morning (Table 20). From the 2nd to about the 10th day, rotifer (a mixture of rotifer that had been fed bakers' yeast and fatty bakers' yeast) was given. On the days that followed until the end of the rearing period the same kind of rotifer (but this time treated in chlorella water) was supplied. The amount of rotifer given per day ranged from 10^7 to 12 x 10^7 pieces. The number was adjusted according to the amount of rotifer left in the water.

Around the 10th day artemia nauplii was added to the continuous supply of rotifer. In the beginning, the amount of artemia given daily was 10^6 pieces. By the end, this gradually increased to 40 x 10^6.

It should be noted that in other fisheries stations hirame larvae were fed with tigriopus, daphnia, and artemia. However, feeding the larvae these additional food items did not affect their growth and survival rates.

In the secondary phase, larval rearing started with the stocking of 15.2-15.9 mm long fingerlings produced in the primary phase (Table 21).

The main food item given was cultivated euphausia. This was supplemented by artemia nauplii and minced food (clam, flying fish, and mackerel). Food was given twice a day at 06:30 hours and at 18:30 hours. The frequency of feeding was four times a day from the 1st to the 15th day after hatching, three times a day until the 18th day, and two times a day after the 18th day. The supply of food was administered in two different places in each cage. The amount given varied according to the food items, duration of feeding, and the tank. However, the total amount of food given was as follows (unit mg):

	Euphausia	Artemia	Clam	Flying fish	Mackerel	Total
Tank no. 1	44743	1102	524	683	0	47052
Tank no. 2	62852	6723	2955	292	599	73421
Total	107595	7825	3479	975	599	120473
Percentage	89.3	6	2	0.8	0.5	100

These figures show that 55% of the larvae stocked in the cages survived by feeding on 95% live food despite the sedentary habits of the 15-35 mm long flatfish larvae.

Growth

The growth of the larvae in the primary phase was monitored by checking the samples collected from the tank. Three methods were used:

- The volume of the tank water was reduced by one-half to one-third and the fish grouped around the air stones were scooped up by a bucket (15 L).
- These fish were also collected by a siphon (diameter 33 mm).
- The water outlet canal was opened and the fish that went with the water were received in a net placed at the opening of the canal.

The growth of the larvae was different for each tank. The changes in the larvae as they grew are summarized as follows:

- In 3-4 days after being hatched the larvae grew to a length of 2.5 mm. The yolk was absorbed.
- On the 9th day after hatching the larvae were 5.5 mm long.
- On the 20th day the larvae sizes ranged from 7.4-10.2 mm. The right eye had moved to the left side.
- Metamorphosis was completed 24-27 days after hatching.
- In 33-35 days after hatching, the sizes of larvae ranged from 12-16 mm or an average size of 13.92 mm. It was observed that the growth rate was positively related to the water temperature and the supply of artemia.

Being attracted to the light on the surface of the water, the larvae moved vertically in the water in the first 10 days or so. The movement changed to a horizontal one afterward. The larvae with the two eyes fixed on the left side of the head moved mostly in the water just above the bottom and swam upward to feed.

The examination of sampled specimens collected from the two tanks showed the following growth rates. In tank no. 1, 15-mm long larvae grew to 18.0-45.0 mm (or an average of 30.9 mm) during the 24-day rearing period. In tank no. 2 larvae of the same size attained a size of 19.9-43.0 mm (or an average of 30.6 mm) on the 21st day and 28.4-90.0 mm (or an average of 39.8 mm) on the 28th day. It was noted that the growth of the larvae especially in tank no. 2, became irregular after the 10th to the 12th day (the days when the minced food supply started), i.e., the smaller individuals showed slower growth and the larger ones showed a rapid growth. It is believed that at this stage minced food is better than live food for the growth of larvae.

Production

The production of the larvae in the five tanks (primary phase) presented in Table 20 shows the survival rates and the amount of food

given. The survival rates ranged from 24.3-50.5% (or an average of 36.31%). Because of their complexity, the factors affecting the survival rates have not been analyzed thoroughly.

The production of fish in the six net cages placed in tanks no. 1 and no. 2 is presented in Table 21. The survival rate in tank no. 1 (average 72.5%) is higher than in tank no. 2 (average 55.8%). The findings from the two tanks indicate that survival rates show a positive relation to the sizes attained by the fish. However, the other factors that affect this relationship are hardly understood. In this connection it should be noted that the dead fish counted in tank no. 1 during the entire course increased between the 11th and the 14th day and then leveled off. In tank no. 2, the number of dead fish increased around the 11th day and continued to increase until the end of the rearing period. It was also noted that the appearance of dead fish corresponded roughly to the initial supply of minced food.

Disease and Malformation

Swelling of the abdomen and abnormal formation of caudal fin rays were found in some fish, although the frequency of their occurrence was not precisely known. Abnormal pigmentation was observed in 10% of the larvae that had reached metamorphosis. This abnormality was always accompanied by abnormal formation of scales compared to the normal individuals.

Sources: Hiramoto and Kobayashi (1979a, b), Hiramoto et al. (1980 and 1981), Ishida and Tanaka (1976), Midorikawa (1974), Seikai (1980), and Toyama and Shoji (1977).

Common Flounder (Limanda yokohamae) - Pleuronectidae

The common flounder, a right-sided flatfish, known as makogarei in Japan, ranges from Hokkaido down along the Japanese islands to Kyushu and from southern Korea down along the Asian continent to the East China Sea. The species dwells in muddy-sand bottoms some 30 m deep and moves to shallower waters for spawning in January. The makogarei grows to a length of about 35 cm. Like the Japanese flounder or hirame, it is a common food fish. Experiments on the rearing of its larvae started early in 1970. The accounts presented here refer mainly to the experiments conducted at the Yamaguchi Prefecture Inland Sea Fisheries Experiment Station and to the work on larval rearing at the Seto Inland Sea Fish-Farming Centre, Ehime Prefecture. According to the Japan Sea-Farming Association, 733,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The fingerlings reared are used for restocking to the sea, but are not yet used for cultivation in captivity.

Brood Fish

Based on experiences at the Seto Inland Sea Fish-Farming Centre, fully matured female fish are available from the catches of commercial fishing operations in early January and these fish spawn immediately. However, the fish collected in mid-December and kept in captivity for a certain period (37-96 days) were also found to be dependable brood fish.

Seven male and 12 female fish selected from the catches on 14 December were kept in separate tanks (2.6 x 1.3 x 0.6 m) with slow-moving water. The fish were fed annelid worms for the first 10 days and clams afterward. Only five of the 12 female fish were injected with synahorin (125 MU/kg). The injection induced maturation, although the untreated females also matured.

Spawn Taking

The eggs stripped from the female fish were inseminated by the dry method. Adhesive eggs were collected on a palmleaf frame (24 x 28 cm) that was placed in a container. Egg collection took place 37-96 days after the brood fish were placed in the tank. Counting of the eggs was done using the weight method (4500/g).

The following data were obtained from experiments conducted from 1970-73 for length of female fish and number of eggs, respectively: 182 mm, 121,500 eggs; 185 mm, 144,000 eggs; 187 mm, 121,500 eggs; 187 mm, 139,500 eggs; 237 mm, 463,000 eggs; 245 mm, 460,000 eggs; 248 mm, 480,000 eggs; 260 mm, 540,000 eggs; and 272 mm, 900,000 eggs.

Hatching

The palmleaf frame on which the eggs were attached was placed in a hatching tank (120 x 60 x 20 cm). The water was kept stagnant but aerated moderately. The hatching rates in this lot of eggs ranged from 21-97%. The hatching dates (calculated by the number of days after insemination) and their corresponding water temperature readings were as follows: 5 days, 15°C (average); 8 days, 10.7-11.2°C; 10 days, 8.8°C; and 13 days, 6.8°C (average).

Rearing of Larvae

Larvae rearing was conducted in an outdoor tank (150-t capacity) with a heating system and 30 air stones for aeration. Dark curtains were placed over the tank and covered one-third to two-thirds of the surface area. The rearing began on 30 January and lasted for 54 days. Before the rearing process began chlorella was supplied to the tank water at a concentration of 200 x 10^4/cc and small amounts were later added on the 10th and 15th days. The concentration of chlorella was, therefore, 300 x 10^4 on the 4th day, 100 x 10^4 on the 10th day, 30 x 10^4 on the 20th day, and almost negligible after that. New water replaced the tank water every day. From the 10th to the 20th day the amount of new water comprised 10% of the total amount of tank water; on the 20th to the 43rd day, 20%; on the 44th to the 47th day, 100%; and on the 48th day to the end of the rearing period, 200%. From the 5th to the 41st day, the temperature of the tank water was kept at 12-14°C with the help of a heating system.

Feeding

Food given to the larvae included rotifer, copepods (collected from the sea by the light-attraction method), artemia nauplii, and minced sandlance. The duration of feeding included rotifer and copepods from the beginning of the rearing period to the end, artemia nauplii from the 13th day to the end, and sandlance from the 45th day to the end.

The amounts given were: rotifer - given twice a day at about 5 x 10^8/day; copepods - given once a day at 25 x 10^4 pieces/day for the

first 25 days and 70 x 10^4 on the following days; artemia nauplii - given twice a day at 250 x 10^4 pieces/day from the 15th to the 37th day, 800 x 10^4 pieces/day from the 38th to the 49th day, and 1500 x 10^4 pieces on the last 3 days of the rearing period; and minced sandlance - given two to three times a day, amounting to 1 kg/day for the first 3 days, 2 kg on the 4th day, and 3 kg each day on the last 5 days of the rearing period.

The examination of the stomach contents of sampled fish showed the following general feeding tendencies. The 4-6-mm larvae fed on 4-20 pieces of rotifer/day. Those that were 7-9 mm long took in 50-100 pieces and the 10-12-mm ones consumed 200-500 pieces. These findings indicate that the amount of rotifer taken by the larvae corresponded to their growth regardless of the shift in their habits, i.e., from swimming to sedentary. The sedentary characteristic is shown by fish that are 10-12 mm long. The amount of copepods and artemia nauplii that the larvae consumed amounted to only 1-10 pieces/day as shown by the examination of the 7-14 mm long larvae. This finding suggests that copepods and artemia nauplii have low significance as food for larvae. In contrast, the minced fish was completely consumed.

Growth

The growth of the larvae during the 54-day rearing period was fairly smooth - from 3.7-mm hatchlings at the beginning of the period to 18-mm fingerlings at the end. The sizes attained after hatching were as follows: 10 days after hatching, 4.5 mm; 20 days, 6.5 mm; 30 days, 10 mm; 40 days, 13 mm; 45 days, 15.8 mm; and at 54 days (end of rearing period), 18 mm.

The fairly rapid growth shown by the larvae from the 45th day to the 54th day corresponded to the supply of minced fish. Thirty to 35 days after hatching, when the two eyes settled on one side of the head, the 10-12-mm larvae stopped swimming and became sedentary.

Production

The total number of hatchlings in the tank amounted to 29.7 x 10^4 and fingerlings harvested after 54 days numbered 20.7 x 10^4. The survival rate (69.7%) was rather high. It was noted that more larvae died before their eyes moved than afterward.

Diseases and Malformation

Among the total of 207 x 10^4 fingerlings harvested at the end of the rearing period, 2.6 x 10^4 (12.7%) were found colourless and 0.36 x 10^4 (1.7%) had reversed body deformity. The actual survival rate of the normal fish, therefore, was 55.3%, not 69.7% as stated earlier.

Sources: Fukunaga (1976), Jinnouchi (1971, 1973), Jinnouchi and Iwamoto (1973), Minami (1981), and Sato (1971, 1975).

Tiger Puffer (Takifugu rubripes) - Tetraodontidae

The tiger puffer, called torafugu in Japan, is a coastal species that ranges from Hokkaido down along the Japanese islands to Taiwan, and from Peter the Great Bay down to Korea and along the Asian

continent to the Taiwan channel. The species grows to 70 cm in the sea, but the fish in the market, aged about 3 years, usually measure only 40-50 cm in length and weigh 1.5-2 kg.

Despite the high toxicity due to the tetrodotoxin contained in its viscera, the torafugu has been rated as the most delicious marine fish in the country and is sold at a high price in markets and restaurants. However, its supply is limited to the winter months, i.e., December-March.

The stocking of the torafugu after being caught in the sea started around 1935. Artificial spawn taking started in the mid-50s and has continued to the present. It appears certain that the great demand for this puffer will further promote its cultivation. At present, however, the problems in puffer cultivation are the limited availability of the gravid female, i.e., it is obtained only from catches from the sea, and the low survival rate (10%) of the larvae reared. The accounts that follow refer mainly to the work of Fujita (1967). According to the Japan Sea-Farming Association, 3,070,000 seedlings were produced in Japan in 1980.

Uses of Fingerlings

The fingerlings grown to 2-3 cm long in captivity are further cultured in the tank or restocked in the sea. Recently, a marked fingerling liberated in Ariake Bay in Kyushu was recaptured in the Yellow Sea. This incident has encouraged the further restocking of the tiger puffer.

Brood Fish and Spawn Taking

Artificial spawn taking depends on the matured fish selected from the catches of commercial fishing operations, not on fish grown in captivity. Some experiments to grow cultured fingerlings to brood fish have been undertaken, but, so far, no commercial production has been attempted.

Brood Fish

The tiger puffer has matured when it has grown to a length of 40-55 cm and weighs 1.5-2.5 kg. The gravid females, however, make up only 2% of the total amount of fishing catches during the spawning months of March-May. The males make up 20-80%. The peak spawning period lasts for 2-3 weeks in a given regional water. The matured fish caught on the field are brought to the hatchery site. In case the fishing grounds are located far from the site, requiring extended travel time, care is taken to prevent the fish from eating each other. Usually, each brood fish is placed in a single bag that is then placed in a larger container.

Spawn Taking

So far, induced spawning by hormone treatment has not been needed. Eggs are collected by stripping and the sperm squeezed out by pressing. Although the eggs are adhesive they are collected in polyethylene bags or containers and insemination is done by the wet method. Experience has shown that 300,000-500,000 eggs can be obtained from one female and insemination is usually 100%.

Hatching

The fertilized eggs hatch in 7-10 days at a water temperature of 15-19°C. Three types of procedures may be used for hatching puffer eggs:

(a) In a concrete tank (1-3 t capacity) the fertilized eggs are spread on the bottom at a rate of 1-3 eggs/cm^2. The tank is supplied with filtered water that is circulated or the same water is kept stagnant but aerated. The recorded hatching rate for this procedure was 40-50%.

(b) Eggs are spread on a framed wire net (1 mm mesh size) at a rate of 1-3 eggs/cm^2. The frames are placed in a pile inside the tank, which is supplied with moving water. The hatching rate recorded for this method was 40-60%.

(c) Eggs are placed in a glass jar, with aerated water keeping the eggs in motion. The water is changed every day. The stocking rate is 5000-10,000/L of water, and the hatching rate recorded was 90%.

Rearing of Larvae

Larval rearing of the tiger puffer has been developed since the mid-30s, but compared to other species like the red seabream the procedures used are less developed.

A concrete tank with a capacity of 40-50 t was used for the rearing that lasted from 40-50 days. The tank was supplied with filtered, aerated water containing chlorella. The water was kept stagnant for the first 20 days, and, afterward, it was kept moving constantly. The stocking rate of the larvae was roughly adjusted as follows: 10,000-20,000/t of water from the 5th to the 20th day, 5000/t rom the 20th to the 30th day, and 100/t afterward.

Feeding

The following feeding schedule was used: balanus larvae with rotifer was given on the 3rd-15th day, artemia nauplii and plankton on the 7th-30th day, tigriopus with fish larvae on the 17th-30th day, and minced fish or shrimp on the 18th day to the end of the rearing period.

Growth

The larvae in each tank grew at different rates. Generally, however, a 2.6-2.8-mm long hatchling grew to 6 mm 20 days after hatching and to 9-10 mm 30 days after. It then grew rapidly to a length of 45 mm during the rest of the rearing period.

The hatchlings moved vertically in the water and came up to the surface by photaxis. Within 4-5 days after hatching the larvae with opened mouths started feeding. One week later, they were actively feeding and swimming horizontally. Twenty days after, the 6-mm larvae became cannibalistic and began attacking the smaller fish. After 30 days, they entered the fingerling stage (9-10 mm) and grew rapidly. By the 45th-50th day, they were about 25 mm in size and were ready for restocking or further rearing in captivity.

Production

Two critical periods were observed during the tank rearing. The first occurred between the 12th and 15th days after the start of the rearing period. The second happened between the 20th and 30th days. By counting the number of dead fish the mortality rate in the first period was recorded at 50-70% and at 10% in the second period. The survival rate at the end of the rearing period (40-50 days after hatching) was usually as low as 10%. A high survival rate of 20% was seldom reached.

Disease and Malformation

Symptoms of skin swelling, white spots, and other diseases were observed. However, these did not adversely affect production in general.

Sources: Fujita (1962a, b; 1965; 1967).

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